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Enhanced Arc Hydro for South Florida Water Management District

Task 1.2 Requirements Definition and Conceptual Design

PBSJ

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Requirements Definition and Conceptual Design for Development of an Extended Arc HYDRO Framework for South Florida

Introduction

This effort is focused on the common and unique needs of four specific projects at the South Florida Water Management District (the District). These Four Projects represent a broad cross-section of the District's Primary Mission. The Four Projects are:

- Operations Decision Support System (Ken Stewart)
- Regional Simulation Model (Jayantha Obeysekera)
- C-4 Basin Flood Modeling (Ken Konyha)
- Kissimmee River Restoration and Hydroperiod Analysis (Chris Carlson)

Details of these projects can be found in Appendix B. The important thing to recognize here is that:

- All four projects share a common need for timely and accurate data about the hydrologic and hydraulic systems of South Florida.
- All four projects have overlapping needs that could be met through a common data structure.
- All four projects could both feed results into and utilize results from a common data structure that would support the needs of these projects and the needs of District decision makers.

The starting point for this project is the nationally recognized and accepted GIS data model for hydrology—the Arc Hydro Geodatabase and the Arc Hydro Tools for data input and maintenance (Appendix C). The project approach is to extend the Arc Hydro framework to meet the common needs of the Four Projects while coordinating through the District's Enterprise GIS team to ensure that these efforts also coincide with the larger interests of the District in implementing an Enterprise GIS.

This document represents the completion of **Task 1** of the Enhanced Arc Hydro Requirements Definition and Conceptual Design. **Task 2**, referenced throughout the document, is for Implementing Enhanced Arc Hydro within the Districts Enterprise GIS environment. **Task 3**, also authorized under this workorder and referenced in this document, is for implementing a Hydroperiod extension to Enhanced Arc Hydro and tools for Hydroperiod Analysis. The goal of this document is to synthesize extensive input from many District participants, existing documents, and sample data. The synthesis is in two parts- the Requirements Definition is Part 1 and the Conceptual Design is Part 2.

1 Requirements Definition

1.1 Problem Definition and System Justification

The fundamental problem to be addressed by the Enhanced Arc Hydro Geodatabase is articulated by the SFWMD GIS Working Group (GISWG) in the Executive Summary of the E-GIS Plan; Version 2002.11.02 and is quoted here:
The GISWG documented that project-level coordination of GIS resources was resulting in an inability to share information across organizational boundaries, the development of corporate data that does not meet the needs of organizational units that depend on it, and a waste of resources through duplication of effort.

This problem was identified and documented by the GISWG as a system-wide problem, and it is an excellent statement of the primary issue that is addressed by this effort. Each of the Four Projects requires extensive data-- in the absence of a common data model, each project is forced to take current GIS data layers and adapt or modify them to meet the individual needs of the project then add new data in a project-specific format. This begins a spiral of increasing divergence and incompatibility between the project datasets. The superior approach is to identify a data model for each project and build a common structure and procedures based on common needs. In this way, a framework and procedure is introduced that not only serves the individual project data needs but drives projects towards further convergence and further identification of shared interests.

Once projects share a common data model, it becomes possible to share results in a hydrologic framework linked to the common geographic features. Sharing results is what all the effort is about. A shared hydrologic framework is both a key feature of the current project and provides its ultimate justification--the primary missions of the District are advanced by making these results available to decision makers at all levels, in a standard, shared format. Scientific Water Resources Management can then be based on up-to-the-minute, modeled, reproducible analyses and forecasts, available through a centralized data framework. This is in sharp contrast to results scattered in a variety of formats in project reports and datasets that must be manually rolled up into static summary documents.

Rather than define additional specific problems that were identified during project analysis, the specific problems identified have been formulated into goals in the next section.

1.2 Goals

The basic goal of the project is to extend the Arc Hydro data model to support the needs of four representative projects from four business units at the District:

- **Operations Decision Support System** (ODSS), which is the entity operating the District's water systems
- **Regional Simulation Model** (RSM), which is a regionalized model of hydraulic head and water flow
- **Flood Hydrology and Hydraulics** (H&H), which is a localized analysis of flood conditions for particular areas within the District, here represented by the C-4 basin.
- **Hydroperiod Estimation**, which is being undertaken in the Kissimmee River Division, but which is intended eventually to be used elsewhere in the District as RECOVER projects are implemented.

These four projects represent a starting point and foundation for the Enhanced Arc Hydro Framework, as shown in Figure 1.2-1

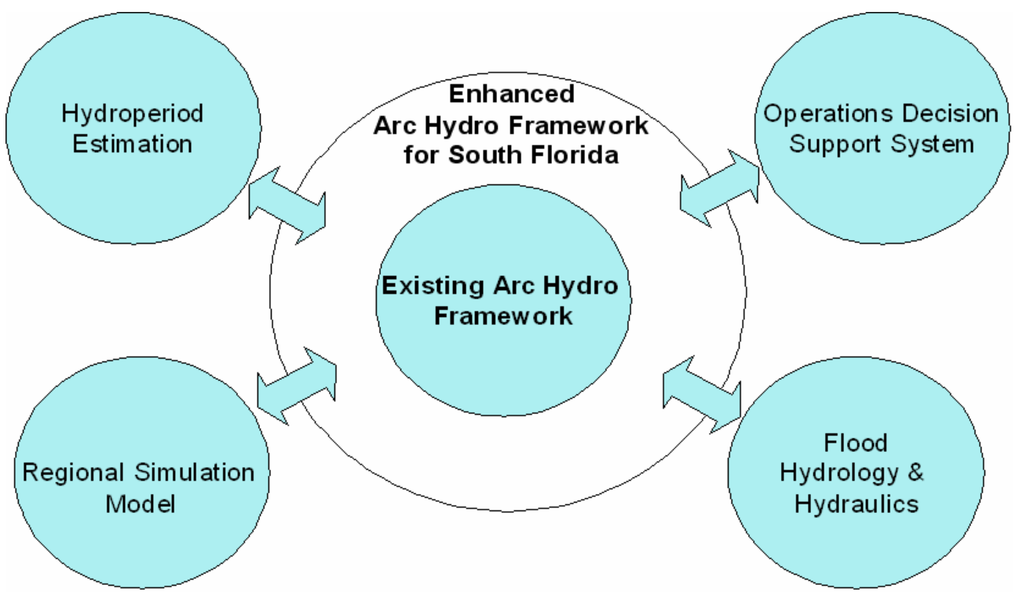

Figure 1.2-1 Four business units of the SFWMD linked through an Enhanced Arc Hydro Framework

After intense review of the project needs—both data and functional needs—the following list of goals was compiled. Details will be discussed under Solutions Strategy and the Conceptual Data Model. The goals are divided into the immediate goals to be implemented during Task 2, and long-term goals that the geodatabase design must be able to accommodate.

Overall Goals:

1. First and foremost the goal is to extend the nationally recognized Arc Hydro Geodatabase to meet the data needs of South Florida, as represented by the Four Projects.
2. The initial implementation of the geodatabase must provide an Enhanced Arc Hydro Toolset for basic data input and maintenance, and load sample data.
3. The Enhanced Arc Hydro geodatabase will provide a framework for shared hydrologic information in support of Scientific Water Resources Management. This framework is built on and linked to the geographic framework and includes a relationship to allow linking back to the data source
4. The solution will include specifications for how the Arc Hydro geodatabase will interface directly with the individual projects (but developing these interfaces is not part of Task 2).
5. The solution provided will be generalized where possible so that it is extensible well beyond the needs of the Four Projects to encompass the needs of the Enterprise.

Specific Goals to be met under Task 2:

1. The Enhanced Arc Hydro Geodatabase must support the following specific needs for South Florida. Items 1.1 – 1.4 are already supported by standard Arc Hydro:
   - 1.1. Provide a framework to integrate multiple hydrologic layers and maintain relationships between layers. (For example linking gages to their water bodies and to their basins).
   - 1.2. Support a non-dendritic hydrologic network with user-defined flow-reversals. Support for linking to a future system that provides dynamically-defined flow direction.
   - 1.3. Be compatible with a system for distributed data maintenance based on assignment of data stewards.
   - 1.4. Support a unique HydroID for every feature in the District, subdivided by basin (Currently supports up to 428 basins with up to 10 million features each, or 4289 basins with 1 million features each).
   - 1.5. Include support for special geographic features and attributes of the South Florida hydrologic system as identified in individual project data requirements. Examples are ASR wells, and linear conduit that cannot be modeled as open channel under flood conditions.
   - 1.6. Provide a time-series framework to integrate point time-series, time-indexed grids, and time-series defined on features.
   - 1.7. Provide “hooks” and strategies to link with time-series data that are stored in existing Relational Database Management Systems (RDBMS). Examples: Rainfall, Gage data, SCADA output.
   - 1.8. Provide time-indexed geographic features. Because so much of the South Florida hydrologic/hydraulic environment is manmade, it is important to

maintain beginning and ending dates of service, similar to a Utility, as well as the dates that geographic features are created and destroyed.

1.9. Provides Linear Referencing. The network of canals and channels frequently needs to be subdivided in different ways depending on the project and the scale. Linear referencing is the best method for attaching multiple sets of data to dynamically measured portions of a single network.

1.10. Data Certification. The geodatabase will address the specific data quality and data certification needs of a scientifically-based water management system. Examples:

1.10.1. There are many data layers that will be entered and maintained from a variety of sources. Relative quality of individual records or record groupings need to be assessed to resolve conflicts between data layers

1.10.2. Data need to be certified for use at different scales and/or for different common applications.

1.11. Support for maintenance of historic "snapshots" of portions of the Enterprise geodatabase for project archives or for developing "what-if" scenarios.

1.12. The geodatabase will be accessible using standard RDBMS toolsets as well as through ArcGIS.

2. The project must provide an Enhanced Arc Hydro Toolset for data input and maintenance that meets the following goals:

2.1. Adapt tools from the Arc Hydro Toolset to Enhanced Arc Hydro.

2.2. Automate assignment, and uniqueness/connectivity/consistency checks of HydroID.

2.3. Support Check-out and Check-in of data by Basin and synchronizing HydroID.

3. The Enhanced Arc Hydro geodatabase will provide a framework for shared hydrologic information in support of Scientific Water Resources Management that meets the following goals:

3.1. The hydrologic framework will address water balances, heads and flows as the key hydrologic data to superimpose on the geographic data.

3.2. The hydrologic framework will include links to the source data to permit review of inputs and methodologies (e.g. which model was used).

3.3. The hydrologic framework will be structured to permit comparison of water balances and to allow conservation of mass calculations. This includes comparison between different sources for the same location and time step. For example the volume of water in a canal as indicated by operations and as modeled by Flood Control.

3.4. The framework will permit the investigation of the effectiveness of the gage network, and the extent to which adding or removing gages will change the precision of water management (geostatistics using ESRI Statistical Analyst-implementation in Future Tasks)

3.5. The framework will provide a standardized mechanism through the design of customized model interface geodatabases, for the integration of other hydrologic models and components not presently a part of the Four Projects

Long-term Goals

- Support for a proposed hydroperiod tool to be developed under a separate Task.
- Support for automated interfaces between the Four Projects and the Enhanced Arc Hydro Geodatabase.
- Identification of additional opportunities to share functions and applications between projects.
- Support for storage of 3-D data to represent integrated high water, shallow water, and groundwater heads and flows. This is a key goal and is addressed in detail in 2.3 Conceptual Design. [1.] The core Arc Hydro Framework implemented in Task 2 will provide the structure to support this goal. The full implementation of the system will be part of a future task drawing on project-specific geodatabase links, and involving implementation of geodatabases or Enterprise database links for supporting models such as RSM and FEMA Flood Mitigation modeling.
- Provide a Hydrologic Framework compatible with the following ultimate goals for the system:
    - Construct water balances for spatial units in Arc Hydro
    - Calibrate modeled data with gage values to get updated head and flow fields
    - Hydrologic forecasting and prediction

The Core Arc Hydro Framework implemented in Task 2 will provide the foundation, links and strategies for implementing these ultimate goals during future tasks.

1. Note the E.J Wexlar conceptualization for hydrostratigraphy that is highly compatible with Arc Hydro. For future groundwater component.

1.3 Constraints

As constraints are encountered during the detailed design and implementation under task 2, they will be documented in project progress reports in order to be addressed/resolved in cooperation with the District.

System Constraints fall into three primary categories:

- Hardware and Operating Environments (Operating Systems, RDBMS Platforms, Network).
  - Existing
  - Planned

- Functional Constraints (Existing User Base, Source Data Limitations, Intended Use, Reporting Requirements, etc.)

- Funding and Administrative Constraints (competing needs, priority changes, re-organization and management changes).

Hardware and Operating Environment constraints will be initially reviewed and addressed at the start of Task 2. Resolution of these constraints will take the form of either modifications to the system to remove the constraint or modifications to the implementation to work within the constraint. These constraints and solutions will be addressed in the Detailed Design document. Additional Hardware and Operational Constraints uncovered during the implementation will be documented to ensure that all options and required actions on the part of the District or the Consultant to address the constraints are identified and implemented without delay or confusion.

Functional Constraints will be noted during the detailed design at the start of Task 2 and addressed in the Detailed Design document. Functional Constraints will be encountered during the implementation and will be documented and addressed through Project Progress meetings. The consultant will make recommendations to the Project Team to resolve any issues so the project may move forward in a timely fashion.

Funding and Administrative Constraints need to be discussed openly and pro-actively. In many cases these are beyond the control of the Project Team; however, strategically- planned presentations to upper management, phased deliveries to show project progress, and inclusion of project progress in internal newsletters, are examples of ways to keep team members enthusiastic and retain support from upper management. The consultant will provide as requested presentation material and interim products, as well as attend special presentations if needed. Input from Project Team members on aspects of the project that are current “hot buttons”, or relevant upcoming internal events at the District, can help the Consultant to plan ahead for quick response.

1.4 Functions to Be Provided

The following list represents key functions that must be supported by the Enhanced Arc Hydro Geodatabase. Functions are prioritized as follows: Priority 1 will be implemented during task 2, priority 2 is to be included in task 2 if budget allows, priority 3 is for future implementation:

- The capacity to develop and maintain a portion of the geodatabase for a sub-region of the district, and then to smoothly integrate that with the district-wide geodatabase. *This is part of disconnected editing. It is to be implemented and tested during Task 2.*
- The ability for project-level geodatabases to use more detailed spatial information than a subregional or district level geodatabase, and be able to exchange hydrologic information with sub-regional or district level geodatabases. *Project-level geodatabases are not part of Task 2. Task 2 will provide the hooks and specifications for these interactions.*
- The ability to have district-wide spatially distributed water balancing, as provided for by the RSM model, be an input to other models and analyses, including the ODSS, Hydroperiod tools and flood management. *While the project-level geodatabases and model interfaces are not part of Task 2, the framework and attributes to store sufficient hydrologic information in Enhanced Arc Hydro to permit water balancing is a part of Task 2.*
- The capacity to define from gage-adjusted radar rainfall information the amount of rain falling in the drainage area contributing to each water control unit. *The capacity to implement this feature as a tool will be included in Task 2, generalized to include distribution of many types of hydrologic data to user-defined drainage areas. A tool to assign gage-adjusted radar rainfall to the contributing drainage area of a WCU is priority 2 (See tools under Section 1.*7.2.
- The construction of water control unit "systems" which connect all the spatial features influencing the performance of a particular water control unit. *The relationships to define these systems will be included in Task 2.*
- Support for hydrologic and hydraulic modeling of water heads and flows through the drainage areas and water control units. This will be by using the RSM model for planning purposes, and by using this model or others for operational purposes. *Specific Interfaces with hydrologic and hydraulic modeling tables and/or project geodatabases are not part of Task 2. Task 2 will provide the Enhanced Arc Hydro geodatabase with geographic and network features required for modeling, with attributes such as length and slope that are common to all models, and with hooks to timeseries so that heads and flows can be linked to Arc Hydro features.*
- Support for flood management and planning during extreme events, including historical storms, and standard design flood events. This will include the linkage of the extended Arc Hydro framework to standard flood hydrology models, such as XP-SWMM, and perhaps later the HEC and

DHI flood modeling systems. *Task 2 will implement Enhanced Arc Hydro with the capacity and data structures to link geographic features with model results to show heads and flows. Actual links to models and/or live results for flood management and planning will be implemented during future tasks.*

- The capacity to transform time series data from recorded time series in the external database systems to time series of map attributes, grids and feature classes, such as inundation maps. All these functions are needed to support the computation of statistics, graphs and maps of hydroperiods and hydropatterns of wetland inundation. *These tools are to be developed as part of Tasks 3 for those time series required specifically for Hydroperiod. Task 2 will include the data structures for linking from Arc Hydro to an example Enterprise database (DBhydro) and a generalized methodology for linking to other Enterprise databases.*
- The ability to link and compare time series produced by hydrologic models and those measured at gages to calibrate and validate model performance. *Task 2 will provide the hooks and data structures to perform these comparisons. The tool to import Monitoring Station time-series to Arc Hydro is a high priority item that will be implemented during Task 3 in parallel with Task 2. Interfaces to model results are for future tasks.*
- Spatial and autocorellation statistics under future tasks.

1.5 User's Characteristics

Understanding the users of the Enhanced Arc Hydro Geodatabase is important to the design of the geodatabase, to the design of Enhanced Arc Hydro Tools, and to future implementation of user interfaces. Future user interfaces will serve specific needs ranging from model interfaces to Executive Summaries.

Identifying the users is one aspect of discovering how the data will be used. Detailed user characteristics will primarily impact application development and future user interfaces. The keys for implementing Enhanced Arc Hydro are determining classes of users, which data they will need, and which data they will be responsible for maintaining. These functions are already defined in the *SFWMD GIS Data Management Operations and Maintenance Guide (Version 2.0, July 2003).* Enterprise GIS will play a key role during the implementation of Enhanced Arc Hydro by helping to identify key members of these user classes. This will serve both to assist in efficient implementation and provide a pool of users to participate in training and testing.

Basic characteristics of the primary users from the Four Projects are shown in the Pre-Charrette Questionnaire Results (Appendix D). These users are typically sophisticated, both using and creating GIS data, and are familiar with

GIS Software. They are applying GIS to solve scientific and engineering problems using system models, real-time data and model results. However, the larger goals of this project – providing a framework that will support operations, flood mitigation, environmental restoration, and the Regional Simulation Model; a framework that will ultimately be available to decision makers for Scientific Watershed Management – will require that the needs of a larger group of users be recognized as well. The initial sub-task of Task 2 includes identifying data sources and requirements. This includes a more detailed map of users, user data requirements, and data stewardship. Identifying these characteristics will be a joint venture between the consultant and E-GIS.

1.6 Development, Operating, Maintenance Environments

ArcSDE is dependant on the underlying database. Minimum hardware recommendations will always be sought from the database vendor in the first instance. There are many factors that impact minimum system requirements for server focused products.

An ArcSDE software installation requires approximately 40-160MB of hard disk space depending on platform and database being utilized. Memory requirements for the ArcSDE services may range from 1MB to 40MB but will vary. In addition, memory requirements per ArcSDE connection may range from 100kb to 40MB per ArcSDE connection but will vary depending on several factors including your configuration choice and database usage. If using ArcSDE in the application server configuration, your server memory requirements will be larger. If using the direct connect configuration, your ArcSDE server memory requirements will be less, but your client machine memory requirements will be larger. Users conducting a lot of edits or selections will often consume more memory than those users simply displaying data from the database.

In order to properly plan the implementation, PBS&J will need to know the following:

Network Configuration

1. Schematic Network/Server Diagram(s), including relevant server names and functions, connection types (Fiber, 100GB, T1, etc.) and including relevant project servers. An expansion of Figures 4 and 5 from the SFWMD Data Management Guide would be ideal. To include specific relevant workgroup and project servers (both existing and proposed) and network information, See Figure 1.6-1 below.
2. Network Operating System(s) and Version(s)
3. Known Network Performance Issues

Server Configurations (Servers shown in Figure 1.6-1 below plus relevant workgroup and project servers)

1. Network Operating System and version
2. Drive Array size and configuration
3. Number of Network connections and type
4. Memory size
5. Oracle version and number of instances for Oracle servers
6. ArcSDE version and configuration information for ArcSDE servers – standard geodatabase load parameters, etc. (any Oracle spatial connections?)
7. Projected/proposed number of simultaneous ArcGIS edit session connections, and ArcIMS connections.
8. Distribution of current geodatabases and layers (current data catalog).

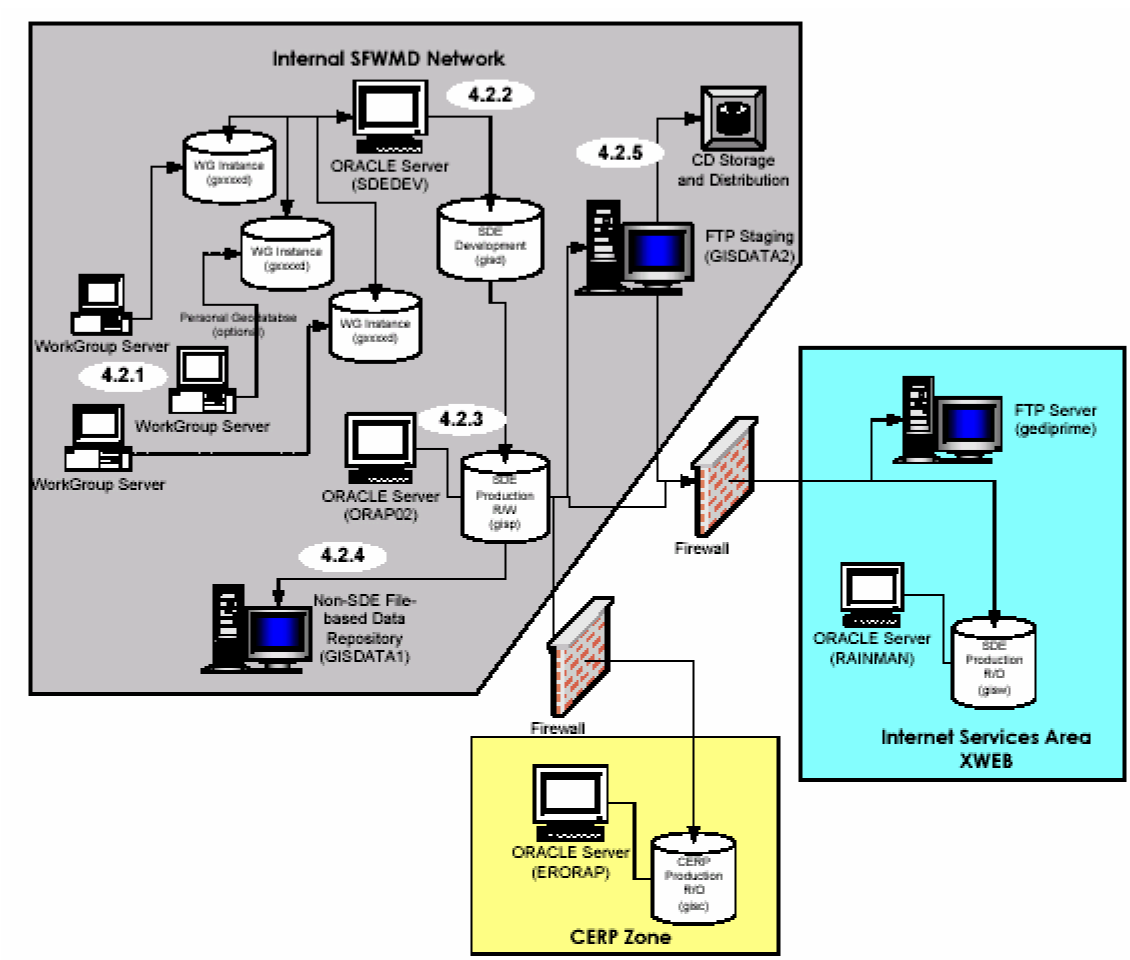

Figure 1.6-1 Generalized Schematic of SFWMD SDE servers (Figure 4, pg. 17; SFWMD GIS Data Management Operations and Maintenance Guide; Version 2.0; July 2003).

1.7 Solutions Strategy

The core solution builds on:

1. The Arc Hydro geodatabase as described in Arc Hydro-GIS for Water Resources, ESRI Press 2002.
2. Arc Hydro Tools
3. "Implementing Arc Hydro", Chapter 9 of Arc Hydro, GIS for Water Resources.

In order to customize and extend the Arc Hydro geodatabase to meet the unique needs of the District, the Four Projects were analyzed during Task 1 to build a conceptual geodatabase model built on Arc Hydro. The resulting conceptual framework (in Section 2.3 of this report) both incorporates and unifies the shared needs of the four projects. By analyzing project data, project results, user needs, and extensive background information provided by project participants, both common elements and powerful opportunities for cooperation have been identified. The implementation will comprise:

- Prototyping the conceptual framework with data from the District at the Consultant sites clarify based on specific data decisions
- Modifying the design based on the prototype implementations
- Documenting the detailed Enhanced Arc Hydro Data Model in Unified Modeling Language under Microsoft Visio
- Simultaneous to prototyping the data model, cooperate with E-GIS to document the Development, Operating and Maintenance Environment
- Implement the UML in a pilot geodatabase on the District's SDE Development Server
- Utilize the Arc Hydro Tools and ArcGIS to load sample data*
- Implementation and performance testing of the Enterprise geodatabase
- Refine and tune Enterprise geodatabase
- Provide documentation and training for translating existing data into the geodatabase, building the network, and relating features to the network. Conduct initial training/testing with key data stewards and power users.

* Sample data to be loaded are outlined in Section 2.5 under Implementation Priorities.

1.7.1 Enhanced Arc Hydro

Individual project data and data models were analyzed in Task 1 to identify key components. The following key elements have been identified as areas where the Arc Hydro data model will need to be adapted or extended:

1. *HydroNetwork: The HydroNetwork will be based on the ODSS data framework and a Schematic Network representing Water Control Units. This will form the backbone of the Enhanced Arc Hydro Network.*

    a. HydroEdge
        i. Shoreline (Attribute can delineate lake, coast, etc.)
        ii. Flowline *(Attributes will delineate streams, centerline through lakes and canals, pipe, etc.) Measures will be added.*
    b. HydroJunction
        i. In order to mirror the distinctions made in ODSS and RSM, HydroJunctions will have two subtypes – Controlled and Uncontrolled.
    c. HydroNetwork_Junctions *(no change)*
    d. Schematic Link-Node Diagrams
        i. As needed for conceptualizations and project interfaces.
        ii. Provide Separate Link-Node Schematic Diagrams for Water Control Unit Nodes and Links; Hydraulic Modeling Nodes and Links. Note the ability to maintain feature relationships through HydroJunctions without initially requiring geometric coincidence. This will be an important feature for relating different layers that have not yet been topologically rectified to each other.

2. Drainage
    a. Regional Drainage Areas (Arc Hydro Basins)
    b. Basin boundaries (Use modified USGS Basin Nomenclature; Basins linked to HydroJunctions; assign HydroID's by Basin; Link detailed project geodatabases to core Arc Hydro by Basin).
    c. Sub-basins (Identify concurrence/overlap between Flood Control Sub-basins, Water Control Unit drainage areas, and RSM cells. RSM Cells may be useful to define WCU drainage areas within Basins. Could support dynamic assignment of drainage areas to different WCU's depending on conditions in a lookup table).
    d. Drainage lines
    e. Drainage outfalls
3. Hydrography
    a. Points representing Dams, Bridges, Weirs, *Monitoring Points, Structures*, User Defined Points, etc. can contain details specific to the feature and be related to a Hydrojunction on the HydroNetwork.
    b. Waterbodies (related to HydroJunctions in the HydroNetwork*). Include Lake, Tidal, Marsh and Canal Segment polygons as water bodies to accommodate ODSS and RSM. Investigate relationship between canal segments in RSM and canal segments in ODSS.*
    c. Hydro Response Units *(Investigate relationship between RSM PseudoCells and Hydrologic Modeling HydroResponse Units)*

   d. Hydrolines and HydroPoints (administrative or other linear features to show on the map but not included in the HydroNetwork or represented by HydroEdge).
4. Channels
   - 3-D Polyline Cross-sections and Profiles with HydroID's and links to HydroJunctions and stream measures.

5. Time Series –*In order to accommodate the data needs and results from Hydroperiod Analysis, Flood Control, Operations and the Regional Simulation Model, a fundamental addition to the conceptual model will be to expand Time Series. Time Series will be divided into four basic types*. Only type b. is currently part of Arc Hydro:
   a. TimeSeries – *an object class containing (Time, Value) pairs which will be linked to a catalog using a unique identifier for each time series. Most likely this structure will be designed to be conformal with DBHydro so as to facilitate exchanging data with DBHydro. The details of this structure have yet to be worked out.*
   b. Attribute Series – an object class containing (FeatureID, Time, Value) triplets in the format of the current Arc Hydro time series format as illustrated in Figure 2.3-1. The shape of the features represented by these attribute series is fixed in time, just the attribute is varying in time.
   c. Feature Series *– a feature class containing (Shape, Time, Value) triplets in a format consistent with an Attribute Series. The shape of the features in a feature series can vary with time, as contrasted with an Attribute Series whose shapes are time-invariant.*
   d. Raster Series – *a time-indexed Raster Catalog, as illustrated in Figure 2.3-4*

   Additional reasons for including a triangular mesh in Enhanced Arc Hydro:
   - *Runoff units can be based on a triangular mesh derived from RSM and will provide a framework for Attribute time series.*
   - *A triangular mesh will serve as a spatial framework to associate discreet runoff areas with water control units, basins, and HydroJunctions.*
   - *A layered triangular mesh will provide a 3-D geometric framework for reporting heads and flows throughout the district, and for distributing results from models into a common geometric framework.*
   - *Note that while Project results can be distributed to HydroAreas through the triangular mesh, project input datasets will also be linked to the HydroNetwork and Watersheds through HydroJunctions.*

1.7.2 Arc Hydro Tools

The Arc Hydro tools are to be modified as needed to work with the Enhanced Arc Hydro geodatabase. According to ESRI, the current tools, developed in Visual Basic, are “templates” that will require customization and testing to be implemented as part of a solution. As part of Task 2, the consultant will modify, test and implement at a minimum the tools necessary to load representative data sets into the Enhanced Arc Hydro Geodatabase. A cost estimate for providing additional tools will be included in the Task 2 scope of work, to enable the District to balance the timing of tool implementation with task budgets.

The use of ArcHydro Tools and procedures used to populate the Enhanced Arc Hydro geodatabase will be documented during the implementation and provided as part of the final deliverable for Task 2.

The existing tools recommended for SFWMD are presented by their grouping in the Arc Hydro Tools user interface (ArcGIS menus). New Tools recommended for SFWMD are included in a separate section following the existing tools. The tools are prioritized as follows: Priority 1 will be implemented during task 2, priority 2 will be included in task 2 if budget allows, priority 3 is for future implementation:

Attribute Tools

Tool	Description
Assign HydroID - Priority 1	Assigns a unique identifier (HydroID) to a feature. HydroID is unique across a geodatabase.
Generate From/To Node for Lines - Priority 1	Generates from-node/to-node topology based on physical line connectivity for a line feature class (does not require hydro network). Nodes are defined as ends of lines. They are not created as a separate feature class, but rather just identified and accounted for internally.
Find Next Downstream Line - Priority 1	Find the HydroID of the next downstream linear feature class based on the default flow direction and store it in the NextDownID field of the feature. The directionality is based on the digitized direction. Connectivity is established by the physical connection of the linear features (does not require hydro network).
Calculate Length Downstream for Edges - Priority 1	Calculate length from the downstream end of a hydro edge to the outlet of the hydro network (requires hydro network). The length is stored in the LengthDown field.

Calculate Length Downstream for Junctions - Priority 1	Calculate length from a hydro junction to the outlet of the hydro network (requires hydro network). The length is stored in the LengthDown field.
Find Next Downstream Junction - Priority 1	Find the HydroID of the next downstream junction and store it in the NextDownID field of the junction feature (requires hydro network).
Store Area Outlets - Priority 2	Identify most likely hydro junction that drains an area. The HydroID of that junction is stored in the JunctionID field for the area feature class.
Consolidate Attributes - Priority 2	Summarize the values of a numerical attribute of a feature class and store them in a field in another (or same) feature class. Relationship between the from and the to feature class is established through related IDs. Operators include sum, min, max, average, median, mode, standard deviation, and count. User specifies the from and the to feature classes, what field to summarize and in what field to store the summarized values. The tool can use the same feature class as both from and to objects to operate on.
Accumulate Attributes - Priority 2	Summarize the values of a numerical attribute of a feature class and store them in a field in another (or same) feature class. The tool selects the upstream objects by tracing either using the geometric network or a NextDownID relationship, and summarizes the selected objects. Operators include sum, min, max, average, median, mode, standard deviation, and count. The selectable objects are either the traceable objects, or can be in an ID-related feature class (using existing relationship classes). User specifies the from and the to feature classes, what field to summarize, and in what field to store the summarized values
Display Time Series - Part of Task 3	Display the values of the selected parameter as a function of time.
Get Parameters - Priority 2	Extract characteristics associated to polygon features: area, average elevation, maximum elevation, minimum elevation, relief, slope, land cover, precipitation.

Network Tools

Tool	Description
Hydro Network Generation - Priority 1	Generate a hydro network (hydro edges and hydro junctions) from drainage lines, sub-basins (catchments), and drainage points. The function updates all the connectivity fields in input feature classes.

Node/Link Schema Generation - Priority 3: This will be done manually during Task 2 implementation and the final components and procedures that evolve specific to SFWMD Enhanced Arc Hydro will be documented for future automation	Generate schematic (node-link) network by connecting centers of catchments/drainage areas and junctions, and junctions and junctions. Connectivity is established through connectivity fields (attributes), not physical connectivity.
Store Flow Direction - Priority 1	Store information about hydro (geometric) network element's directionality into an attribute of the feature matching the element.
Set Flow Direction - Priority 1	Dynamic define flow direction for a geometric network based on digitized direction or an attribute for the feature.

Buttons

Tool	Description
Assign Related Identifier - Priority 2	Interactively assign a value of a field in a source feature to a field in the target feature. User specifies both the source and target feature classes and fields.
Global Point Delineation - Priority 1	Delineate a watershed for a user specified point (interactive) based on a set of preprocessed geographic units tied together by a geometric network. Compute global parameters.
Trace By NextDownID Attribute - Priority 2	Using the attribute relationship established through NextDownID field, trace from a selected location upstream, downstream, or in both directions. The final selected features can include the objects selected through the trace, and/or ID-related objects (using existing relationship classes).

Additional NewTools are recommended to support the Enhanced Arc Hydro Data Model. These are not currently part of the Arc Hydro Toolset. Priorities are set as for Existing Arc Hydro Tools above. Priority 1 will be included, Priority 2 recommended for Task 2 if budget allows, Priority 3 for future task.

Enhanced Arc Hydro - New Tools to be Developed

Import/Export by Translation Table - Priority 1 (see Description)	Translate between any standard ESRI shapefile, coverage or geodatabase and Enhanced Arc Hydro by way of re-usable user-defined translation tables. Include Hydro-ID lookup table for relating unique-identifiers in the outside data to unique HydroID and HydroCodes in Arc Hydro. Priority 3 for model specific stuff and Priority 1 for automating data import of standard sources.
Update Hydro-ID Priority 1 (see Description)	Check Hydro-ID across all features to ensure for uniqueness. Flag non-unique Hydro-ID's for resolution. Assign Hydro-ID's to any elements missing Hydro-ID. Priority 1. Note that uniqueness is to be enforced at the database level so global assignment of Hydro ID's to all elements is the key feature of this tool.
Time Series Translation Tool - Priority 2.	Numerous tools will be required to import Monitoring Station timeseries, rainfall, heads and flows, etc. This can be addressed by a Time Series Translation Tool that reads user-defined templates and translation tables for the source data and the target data formats and automates the translation. Special modules will be required for binary time series formats such as NetCDF that will not be user-defined. The ability to import Monitoring Station Time Series will be included as part of Task 3.
Import DBHydro to Timeseries tool - Priority 1 (under Task 3)	A specific case of Time Series Translation for adding selected DBHydro data to an Arc Hydro Timeseries in a project geodatabase. Required for Task 3. To be implemented in parallel with Task 2 under Task 3.
Data Quality/Metadata Tools -Priority 1 (See Description)	Tools to automate populating metadata attributes and data-quality attributes such as EnteredBy, EnterDate, Source, Quality Certification, BuildDate, InServiceDate, OutServiceDate, RemoveDate Priority 1 on attributes that can be generated automatically such as enterby and enterdate. Priority 2 on other attributes.
Assign Rainfall - Priority 2	Tool to assign gage-adjusted rainfall to a specific drainage area.
Check in/Check out Watershed (SFWMD formerly Basin) Priority 1	Tool to allow users to check out a standard Watershed unit of the Enhanced Arc Hydro Geodatabase for editing, and to check it back in when completed.

1.7.3 Implementing Arc Hydro

1. Detail the conceptual framework
    a. Work with Users from each project team and data gathered during Task 1 to add specific attributes to the Enhanced Arc Hydro data model.
    b. Prototype data model using modest existing data sets representative of the four projects. Incorporate any data or insights revealed on project specific geodatabases proceeding in parallel with Task 2.
    c. Work with E-GIS and Project users to build spreadsheet identifying data sources, data users, and data stewards (for implementation strategy and data upload and maintenance strategy).
    d. Document final prototype using Unified Modeling Language (UML) in Microsoft Visio.
2. Simultaneous to building the UML cooperate with E-GIS to document the Development, Operating and Maintenance Environment, as well as with E-GIS and the Project Team to identify the location of existing data, who is charged with maintenance of each data set, who uses the data when, and its current format.
3. Implement the UML in a pilot geodatabase. Personal Geodatabase.
4. Begin development of additional tools for Enhanced Arc Hydro.
5. Adapt Arc Hydro Tools and ArcGIS to load sample data. Document procedures for future use and to guide the development of automation tools.
    a. Sample Data defined in Section 2.5 of this report.
6. Modify the design based on the pilot implementation
    a. Team demonstration and review of geodatabase relative to goals and functions.
    b. Incorporate comments into design.
7. Implementation and performance testing of the Enterprise geodatabase.
    a. Add links to other Enterprise databases
    b. Core group of project team members test performance in typical scenarios.
8. Refine and tune Enterprise geodatabase.
    a. ArcSDE parameter tuning
    b. Oracle DB tuning.
    c. Geodatabase design tuning.
9. Provide documentation and training for translating existing data into the geodatabase, building the network, and relating features to the network.
10. Conduct first round of training with key data stewards for combined testing and training.

1.8 Systems Acceptance Criteria

As the system is implemented, team members will be given opportunities to review/use the prototype system as a personal geodatabase before implementing in the E-GIS environment. Comments and suggestions will be addressed prior to implementing in the Enterprise environment.

The Enhanced Arc Hydro geodatabase will be a flexible environment that will expand with use as new users and new user needs emerge after implementation. Therefore it is important to clearly define a cut-off point at which the initial implementation will be completed, as well as project milestones. The following system acceptance criteria will be used to define project milestones for completion:

- Task 2.1 - Environment Overview Document Review – System Optimization
- Task 2.2 – Final Project Workplan and Schedule – to be reviewed by District Project Team (Four Projects) and accepted by District Project Manager.
- Task 2.3 – Enhanced Arc Hydro Detailed Design and Toolbox Specifications – To include all items specified in the Final Project Workplan and all tools agreed to in Task 2 Scope of Work. These include the detailed Unifiedl Modeling Language (UML) version of the geodatabase with all attributes defined. The UML must be capable of being exported to a Microsoft Repository and implemented in the Oracle/SDE environment at SWFWMD.
- Task 2.3.2 – Physical Design Document detailing the implementation plan for Enhanced Arc Hydro and the selected Tools in the SFWMD Enterprise. The District Project Manager will review and approve the Physical Design Document.
- Task 2.3.3 – Enhanced Arc Hydro populated with example data as identified in Section 2.5. and Tools as specified in the Task 2 Scope of Work will be demonstrated at the SFWMD after installation and testing on a SFWMD development server. System acceptance will be defined by a functional geodatabase imp[lamented from the approved UML and populated with the specified sample data and tools demonstrated and operational accompanied by an online Tools and Procedures User Manual.

2 Conceptual Design

2.1. Basis of Conceptual Design

The Conceptual Design for Enhanced Arc Hydro is based on the Requirements from Section 1. Key elements of the Conceptual Design are the Data Model and the System Specifications. The specifications describe how the data model is used and maintained and how it interacts with other components of the Enterprise. Specifications are an important component of both implementation and application development.

2.2. Design Guidelines

Good system design must account for many factors, but for database design, the most productive approach, as well as the most likely to succeed, is to consistently verify concepts by working with real data. Data means both the data used to produce studies, and the data that result from those studies. If the data going in are not well organized, verifiable, and consistent, the results will be equally short of the mark. If the system design does not provide for making results accessible and verifiable, then the product will not get support or use by decision-makers. Many factors make up a well-constructed system, but these are keys to the overall success of the project and a project that flourishes with time.

The conceptual data model relies on an iterative process of interviewing users, reviewing how the data are used and in what applications, and testing the concepts with actual data. By tracking where existing data are located, who is responsible for maintaining the data, who uses the data and how frequently, and what format data are currently in, you have the keys to what your database design must accomplish and how it will be populated, as well as the blueprint for integrating the database system smoothly with existing workflow and data utilization.

Frequently this exercise reveals data transfer and/or data maintenance bottlenecks that can be resolved during the implementation of the database system. Additional benefits include opportunities for improving workflows and data sharing, reducing redundant data, improving quality and consistency, and building key relationships between data layers. Data relationships built into the system database structure remove a level of reliance on software, or worse, knowledge kept only in someone's head, regarding the inter-relationships between key features such as monitoring stations and water bodies.

Application design to support the database must be specification driven. As long as specifications are carefully written up front, and each portion of a complex application meets its input and output specifications, it is possible to develop software "objects" that can be tested and debugged individually then integrated into the larger system.

2.3. Conceptual Data Model for Enhanced Arc Hydro

Enhanced Arc Hydro Framework for the South Florida Water Management District

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Nov 10, 2003

The goal of developing an enhanced Arc Hydro framework for the South Florida Water Management District (SFWMD) is to extend the existing Arc Hydro data model to account for the particular nature of water conditions and water infrastructure in the SFWMD, and to link the activities of four business units as discussed in the Requirements Definition Section 1.2.

The discussion that follows is based on research among the project participants and some prototype development. In order to explain the Enhanced Arc Hydro Framework, it is useful to examine how the current Arc Hydro Framework model was developed.

During the Arc Hydro design process from 1999 to 2002, a great many ideas were suggested as to what feature classes and components should form part of the model. Early on, it was clear that these should be divided into areas or components, which later evolved to five: HydroNetwork, Drainage, Channel, Hydrography, and Time Series. The first four of these are feature datasets within the Arc Hydro geodatabase, which represent the "geographic" framework of the model. The fifth component, Time Series, stores the hydrologic information measured or modeled on this geographic framework. This complete Arc Hydro data model comprises about 30 feature classes and tables.

Existing Arc Hydro Framework

It became apparent during the final year of the design process, that it would be desirable to have a simplified version of this complete model, which would contain just the core information that most applications would use. This is called the Arc Hydro Framework data model, which consists of just five feature classes stored in a single feature dataset:

- **HydroEdge** – a complex network edge feature class representing flowlines through streams, canals and water bodies, which is the linear feature class of a geometric network called the HydroNetwork

- **HydroJunction** – a simple junction feature class representing important points on the HydroNetwork
- **MonitoringPoint** – a point feature class representing gages and sampling points for hydrologic information
- **Watershed** – a polygon feature class representing drainage areas
- **Waterbody** – a polygon feature class representing water bodies

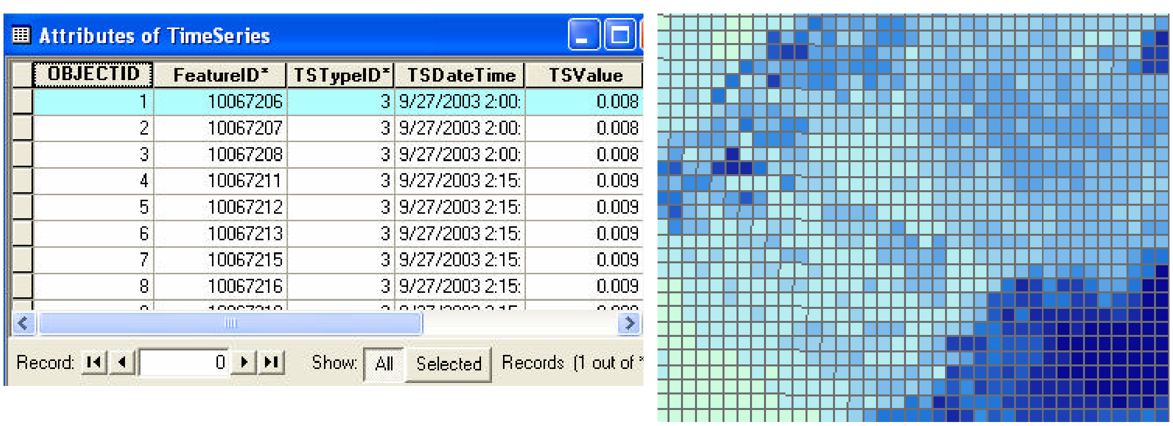
It has become obvious in working with implementations of Arc Hydro that this simplification of the complete model to a core framework is a sound idea because it forms a point of departure for customization to fit particular circumstances. As other feature classes are needed, they are added from the complete model, or are newly defined.

Time Series

A second variant of the Arc Hydro Framework also exists, called the Arc Hydro Framework with Time Series. In addition to the above five feature classes, it includes two time series tables:

- **TSType** – an object class that describes the type of time series
- **TimeSeries** – an object class that contains time series records

Each record in a TimeSeries table contains four fields: a FeatureID to link to the feature being described, a TSTypeID to link to the type of time series data, TSDateTime to record the date and time of measurement, and TSValue to store the time series value itself. SFWMD uses this format to archive its Nexrad radar rainfall data ingestion each 15 minutes over a 2km grid covering the District. ArcGIS has an extension called the Tracking Analyst for displaying time series as animated maps and it has been shown that Tracking Analyst can be used to display animated maps of Nexrad data in Arc Hydro format queried from the District's database (Figure 2.3-1).



OBJECTID	FeatureID*	TSTypeID*	TSDateTime	TSValue
1	10067206	3	9/27/2003 2:00:	0.008
2	10067207	3	9/27/2003 2:00:	0.008
3	10067208	3	9/27/2003 2:00:	0.008
4	10067211	3	9/27/2003 2:15:	0.009
5	10067212	3	9/27/2003 2:15:	0.009
6	10067213	3	9/27/2003 2:15:	0.009
7	10067215	3	9/27/2003 2:15:	0.009
8	10067216	3	9/27/2003 2:15:	0.009

Figure 2.3-1. SFWMD Nexrad data in Arc Hydro format are displayed with the ArcGIS Tracking Analyst

In the book “Arc Hydro: GIS for Water Resources”, a CD-ROM at the back of the book that contains three sets of UML and repositories, one for each of the three forms of Arc Hydro just mentioned - the Arc Hydro Framework, the Arc Hydro Framework with Time Series and the complete Arc Hydro data model

Enhanced Arc Hydro Framework for South Florida

What we are seeking to do for SFWMD is to construct a customized version of Arc Hydro fitted to the Districts information sources and needs. By analogy with the design process just described, it is useful to think of this process in three stages:

- **Geographic Framework** – this is the set of feature classes that contain the geographic framework describing key water features of the District used in common by all of the four business areas being represented.
- **Hydrologic Framework** – this is the set of feature classes and time series tables that is needed to represent hydrologic information about water conditions, either measured or modeled, that is to be shared among the business areas
- **Extension Datasets –** these contain classes that are particular to each of the business areas and linked to the core geographic and hydrologic framework

Arc Hydro Geographic Framework

In examining the geographic information used in the District, it became apparent that the original Arc Hydro Framework model described above is a reasonable representation of the main water features of the District. The HydroEdge feature class is built from the National Hydrography Dataset (NHD) describing the “blue lines” of the District. This is currently being improved in scale from 1:100,000 to 1:24,000 as part of the District’s work with USGS. There are issues about the time variation of flow direction on these lines which need to be resolved by connecting the hydrologic and geographic information, where necessary. The NHD also has a very complete description of water bodies, which is topologically integrated with the HydroEdges. The District has a standard set of drainage areas called Basins. Monitoring Points are normally distinguished in the District as Stage Points or Flow Points but are here combined into a single class with a descriptor, FType, to distinguish the type of Monitoring Point. Because the District has a lot of “plumbing” to move water around the landscape, the geographic framework also needs to include a Structures feature class. The base geographic framework for the District can thus be built as illustrated in Figure 2.3-2.

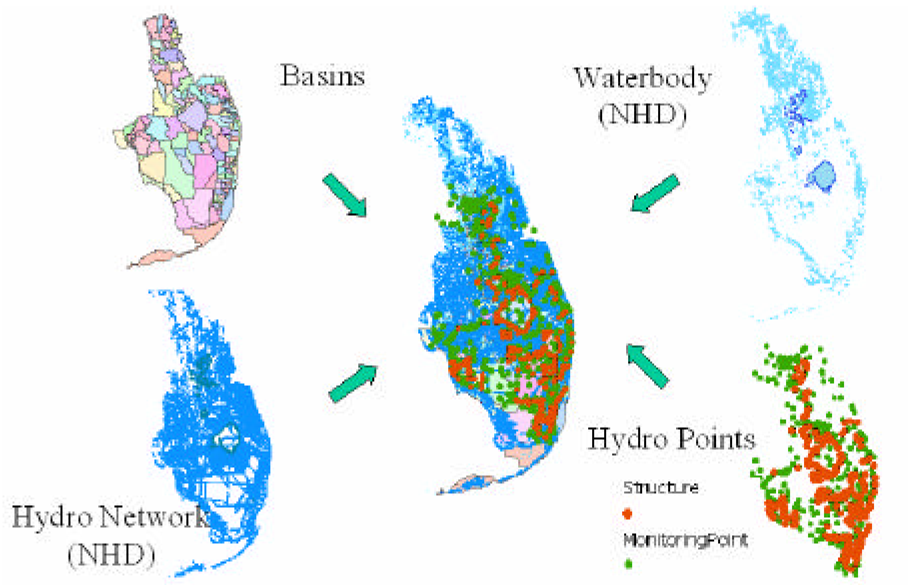


Figure 2.3-2 Arc Hydro Geographic Framework for South Florida

Arc Hydro Hydrologic Framework

Arc Hydro attempts to describe not simply the geographic framework of water features of the landscape, but also the hydrologic information about water conditions, such as rainfall, flows, heads, and water quality. This information can come from measurements, such as Nexrad or stage and flow monitoring devices, or from models, such as the Regional Simulation Model or flood hydrology and hydraulics models. Water management and planning depend on both measured and modeled information.

A key factor in the hydrologic framework for South Florida is the existence of a Regional Simulation Model, which represents water flow over the land surface, shallow groundwater flow, and flow in canals, all solved as a set of simultaneous differential equations on a triangular mesh for the surface water and groundwater flow. Representing a triangular mesh in GIS is not difficult as the Triangulated Irregular Network has existed for many years. However, representation of volume elements in GIS has up to this point been difficult.

In ArcGIS version 9, there is a new concept called “Multipatch” which enables the construction of volume elements as a closed set of surfaces. A simple way to do this is to take a triangulated mesh and vertically extrude it to construct a multipatch for each RSM layer (see Figure 2.3-3 for illustration). To make this concept generic, a set of these features called **HydroElements** has been included in the Enhanced Arc Hydro Framework schema. Although here intended to represent the RSM computational mesh, the HydroElement feature class is a polygon feature class whose shape can represent any area, whether triangles, square or rectangular cells, or arbitrarily shaped polygons (e.g. lakes).

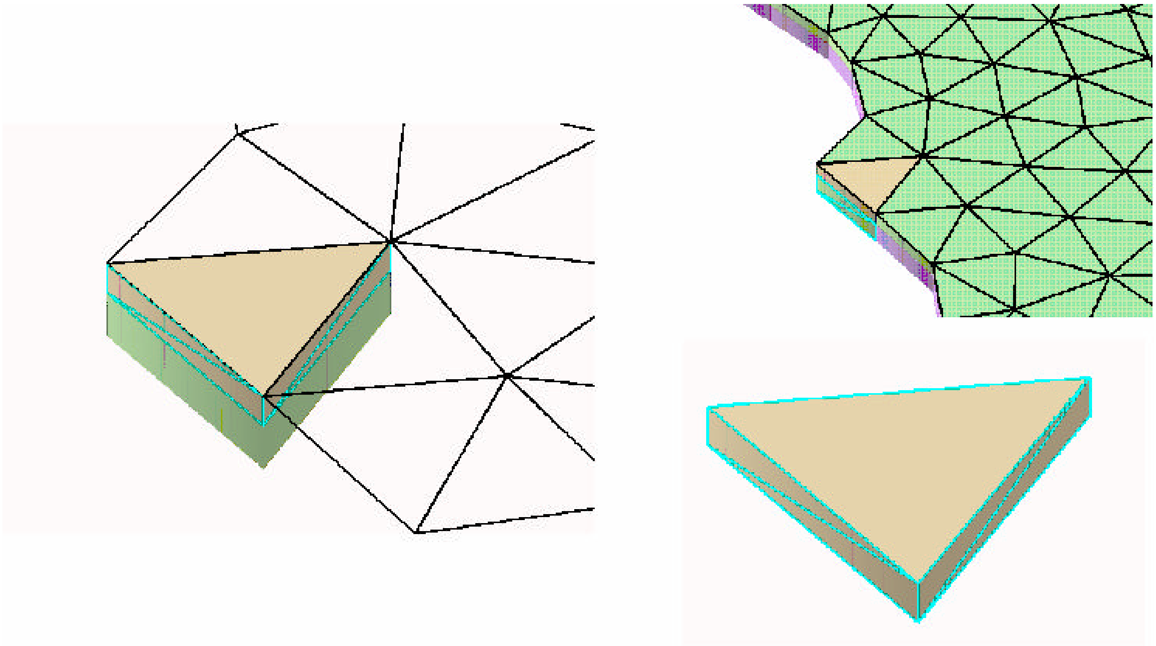


Figure 2.3-3 Triangular HydroElements built in ArcGIS as Multipatches

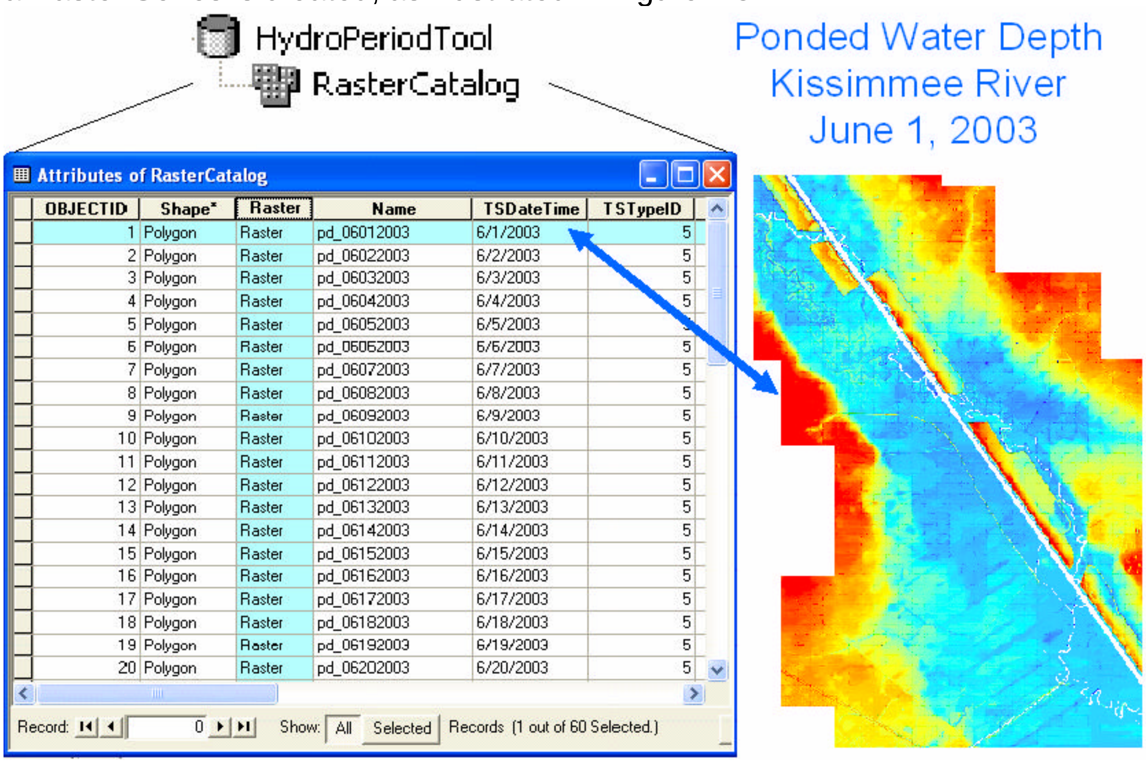
Probably the most critical part of the Hydrologic Framework is the definition of time series. This subject has been intensively studied at CRWR for many months, and after a long period of uncertainty, some clarity in this subject has now emerged. It is intended in an enhanced Arc Hydro representation to support four kinds of time series representation:

- **Time Series** – a sequence of (Time, Value) pairs such as is represented in DBHydro and in hydrologic models such as XP-SWMM. These series are most often associated with geographic features but that is not always so.
- **Attribute Series** – a sequence of (FeatureID, Time, Value) triplets, as is presently contained in the Arc Hydro time series file
- **Feature Series** – a sequence of (Shape, Time, Value) triplets, as is needed to represent the time-varying spatial extent of depth zones for water inundation of land areas.
- **Raster Series** – a sequence of (Time, Raster) pairs, where the value stored on the raster is equivalent to the value field in the other three representations.

In all cases, the type of time series information in the Value field is described separately in a TSType table like the one now used in Arc Hydro.

Feature series can be displayed as animated maps in ArcMap using the ArcGIS Tracking Analyst, and by joining the feature class shape with an Attribute Series (called a "Temporal Layer"), animated maps can also be produced of Attribute Series (this is how Figure 2.3-1 was created).

For example, a set of stage height or water surface elevation Time Series, one for each gage, can be combined to form an Attribute Series for the gage feature class. This series can be queried for values at all gages on a succession of days, and interpolated to produce a Raster Series of water surface elevations, the land surface elevation raster can be subtracted to produce a water depth raster series and the result classified into depth zones, to produce a Feature Series of inundation depth polygons. ArcGIS version 9 introduces the idea of Raster Catalog, which is a table indexing rasters stored in a geodatabase. By adding the TSDateTime and TSTypeID fields to the raster catalog, the format for a Raster Series is created, as illustrated in Figure 2.3-4



OBJECTID	Shape*	Raster	Name	TSDateTime	TSTypeID
1	Polygon	Raster	pd_06012003	6/1/2003	5
2	Polygon	Raster	pd_06022003	6/2/2003	5
3	Polygon	Raster	pd_06032003	6/3/2003	5
4	Polygon	Raster	pd_06042003	6/4/2003	5
5	Polygon	Raster	pd_06052003	6/5/2003	[illegible]
6	Polygon	Raster	pd_06062003	6/6/2003	5
7	Polygon	Raster	pd_06072003	6/7/2003	5
8	Polygon	Raster	pd_06082003	6/8/2003	5
9	Polygon	Raster	pd_06092003	6/9/2003	5
10	Polygon	Raster	pd_06102003	6/10/2003	5
11	Polygon	Raster	pd_06112003	6/11/2003	5
12	Polygon	Raster	pd_06122003	6/12/2003	5
13	Polygon	Raster	pd_06132003	6/13/2003	5
14	Polygon	Raster	pd_06142003	6/14/2003	5
15	Polygon	Raster	pd_06152003	6/15/2003	5
16	Polygon	Raster	pd_06162003	6/16/2003	5
17	Polygon	Raster	pd_06172003	6/17/2003	5
18	Polygon	Raster	pd_06182003	6/18/2003	5
19	Polygon	Raster	pd_06192003	6/19/2003	5
20	Polygon	Raster	pd_06202003	6/20/2003	5

Figure 2.3-4 Raster series of ponded water depth on the Kissimmee River

Conceptual UML Diagrams for the Enhanced Arc Hydro Framework

The Unified Modeling Language (UML) is a format for designing a hierarchical structure of classes and attributes that form a geographic data model. By translating this structure into a repository or set of data tables, a framework is created into which data for SFWMD can be inserted to produce a working data model. In this report, conceptual UML-like diagrams are drawn to illustrate the key elements of an Enhanced Arc Hydro Framework, and Extension Datasets to support the four business areas of SFWMD. In the UML description, the following terms are used:

- **Object class** – a table for storing nonspatial data whose records are indexed by an ObjectID
- **Feature class** – a table for storing spatial data which is an object class plus a Shape field (containing feature geometry)
- **Network feature class** – a feature class geometrically joined to other feature classes through network point-line topology

Figure 2.3-5 shows the present conception of the Enhanced Arc Hydro Framework. It contains 7 feature classes:

- **HydroEdge** – same as Arc Hydro HydroEdge complex network edge class, geometrically connected to HydroJunctions through a geometric network, HydroNetwork.
- **HydroJunction** – same as Arc Hydro HydroJunction simple junction class, except that it has two subtypes, **Controlled** and **Uncontrolled** to differentiate between structures whose behavior can be altered or controlled from those whose behavior is fixed
- **MonitoringPoint** – same as Arc Hydro MonitoringPoint point feature class in which the **FType** attribute is used to distinguish among the different types of monitoring points e.g. flow points or stage points
- **Basin** – same as the Arc Hydro Watershed polygon feature class (note – this Basin nomenclature is used to be conformal with current practice at SFWMD, where Basins are smaller units than Watersheds, but is inconsistent Arc Hydro conventions and with the naming hierarchy of the national Watershed Boundary Dataset where the reverse order is used).
- **Waterbody** – same as the Arc Hydro Waterbody polygon feature class, except that it has 4 subtypes: **Canal Segment, Lake, Marsh, and Tidal**, to differentiate different types of waterbodies existing in the district. Canal Segment is here represented as a polygon to make it consistent with the other waterbodies that are included in Water Control Units. A set of canal segments form a canal, where canals are here indicated by a Name field on the HydroEdge feature class (e.g. Name = C-41, etc)
- **Structure** – this is a point feature class drawn from the Hydrography feature dataset of the complete Arc Hydro model into the Enhanced Framework. It presents point locations of structure features
- **HydroElement** – this is a polygon feature class introduced new into Arc Hydro for South Florida. By building Multipatches on these features, three-dimensional elements are created that are intended to represent elementary control volumes in fluid mechanics, and to store flow, head and volume data describing water movement through the landscape.

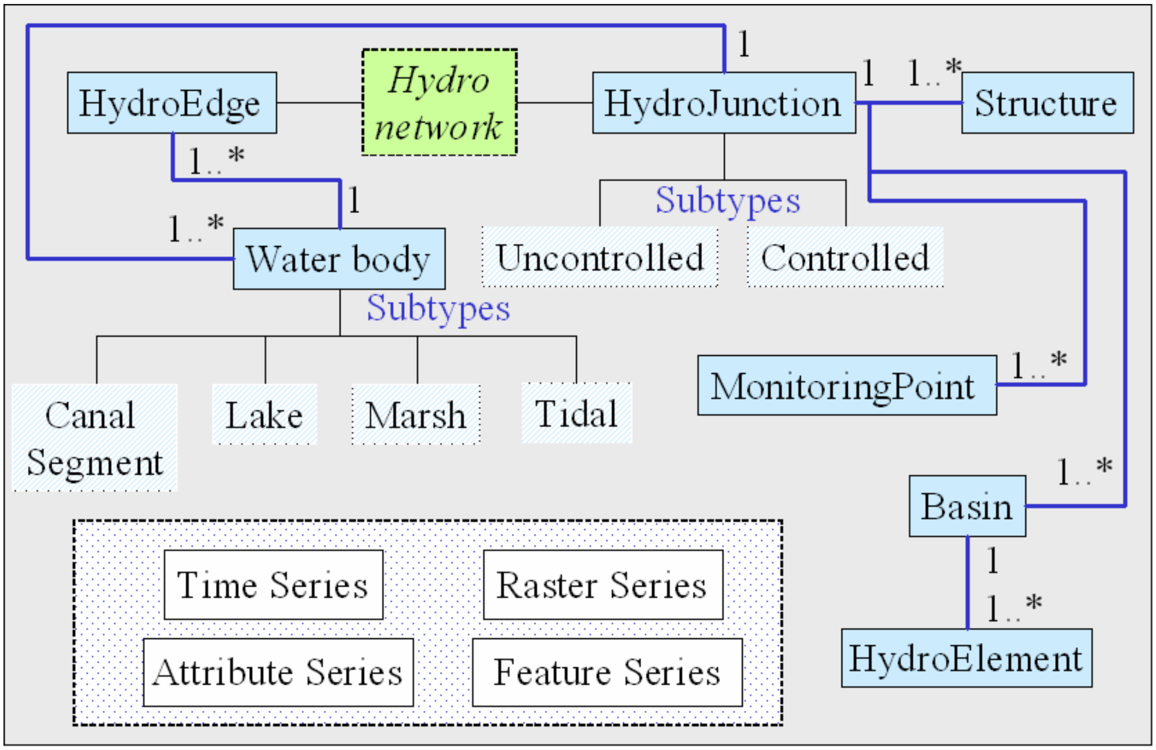


Figure 2.3-5 Enhanced Arc Hydro framework for South Florida

The hydrologic time series information in the enhanced framework is stored in four classes:

- **TimeSeries –** an object class containing (Time, Value) pairs which will be linked to a catalog using a unique identifier for each time series. Most likely this structure will be designed to be conformal with DBHydro so as to facilitate exchanging data with DBHydro. The details of this structure have yet to be worked out.
- **Attribute Series** – an object class containing (FeatureID, Time, Value) triplets in the format of the current Arc Hydro time series format as illustrated in Figure 2.3-1. The shape of the features represented by these attribute series is fixed in time, just the attribute is varying in time.
- **Feature Series** – a feature class containing (Shape, Time, Value) triplets in a format consistent with an Attribute Series. The shape of the features in a feature series can vary with time, as contrasted with an Attribute Series whose shapes are time-invariant.
- **Raster Series –** a time-indexed Raster Catalog, as illustrated in Figure 2.3-4

The Enhanced Framework in Figure 2.3-5 also contains six relationships:

- **Waterbody to HydroEdge** (1 to many) – a waterbody has one or more HydroEdges passing through it. This links the line representation of canals to the polygon representation of canal segments.

- **HydroJunction to Waterbody** (1 to many) – symbolizes the location on the network where a waterbody has an outlet (note: since some waterbodies have more than one outlet, the direction of this relationship might need to be reversed, or it may prove to be superseded by the Waterbody to HydroEdge relationship which connects Waterbodies to the HydroNetwork).
- **HydroJunction to Structure** (1 to many) – this relationally connects the structures to the HydroNetwork even if the structure points are not coincidental with the network lines
- **HydroJunction to MonitoringPoint** (1 to many) – this relationally connects the gages to the HydroNetwork even if the gage points are not coincidental with the network lines
- **HydroJunction to Basin** (1 to many) – this relationally connects the drainage areas to the HydroNetwork at their outlet points (note: some Basins may have more than one outlet point, and the same location may be an inlet to another Basin, so it may occur that this relationship becomes many to many, in which case a link table will be needed as illustrated for the relationship between water control units and structures in the ODSS extension model).
- **Basin to HydroElement** (1 to many) – this relationship documents the tessellation of Basins into HydroElements

UML for ODSS Extension Data Model

An extension data model is a set of additional classes and attributes that are linked to the enhanced framework and provide representation of features critical to a particular business area. The ODSS (Operations Decision Support System) extension data model is illustrated in Figure 2.3-6. This design was worked out using a conceptual paper on ODSS prepared by Paul Ryan. This model contains three new classes:

- **WCUNode** – a simple junction feature class representing key parts of the water control system. There are three types of WCUNodes: Type 1 is a Water Control Unit (a point placed somewhere in the center of the unit), Type 2 is a Structure which separates one Water Control Unit from another, Type 3 represents a Basin whose land area drains into one or more Water Control Units.
- **WCULink** – a simple edge feature class forming the linear segments of a geometric network called the Water Control Network. The main function of WCULinks is to spatially connect WCUNodes. There are two types of WCULinks: Type 1 connects WCUNodes (Type 1 and 2) on the water system; Type 2 connects WCUNodes on the land areas (Type 3 WCUNode) with the appropriate water control unit (Type 1 WCUNode)
- **StructureLink** – an object class that supports a many to many relationship between Water Control Units and Structures

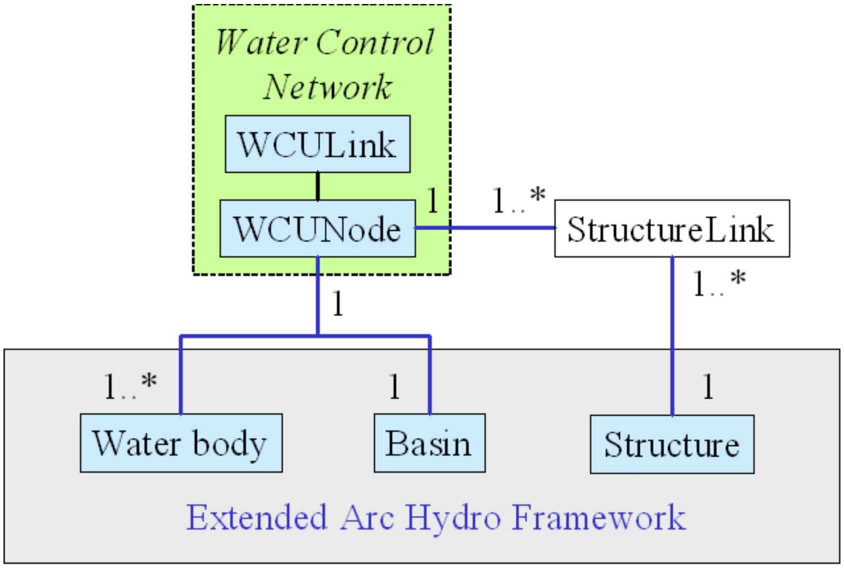


Figure 2.3-6. Extension data model for the Operations Decision Support System

These classes are linked with the Enhanced Framework by four relationships:

- **WCUNode to StructureLink** (1 to many) – this lists the structures bounding a water control unit
- **Structure to StructureLink** (1 to many) – this lists the water control units surrounding a particular structure
- **WCUNode to Waterbody** (1 to many) – this assembles the waterbodies comprising each water control unit.
- **WCUNode to Basin** (1 to 1) – each Basin has a corresponding WCUNode of Type 3 (note: there are about 235 WCU's and 155 Basins so its not possible to uniquely identify the drainage are of all WCU's with this arrangement. There may be utility instead in defining a set of HydroElements that constitute the drainage area of each WCU, and using a 1 to many relationship to capture that association. This may make the connection of rainfall to land surface flow to water control unit flow easier to define).

A prototype has been built of the ODSS extension data model, as shown in Figure 2.3-7. Building prototypes is the best way to check on the validity of conceptual UML designs because implementation with actual data exposes problems that may not be obvious at first glance. This ODSS prototype was adapted from an earlier one prepared by Ben Lewis and colleagues at ATS, and benefits from their work in particular in the definition of the StructureLink table to capture the many to many connection between structures and water control units. A water control unit is a set of one or more waterbodies separated from other water control units by structures capable of altering the head and flow conditions. Within a water control unit, the head at one location cannot be altered independently of the head at any other location (i.e. within a WCU, the hydraulics are spatially continuous). A water control unit can have many structures bounding it. By definition, a structure separates at least two water control units. Thus the relationship between structures and water control units is many to many.

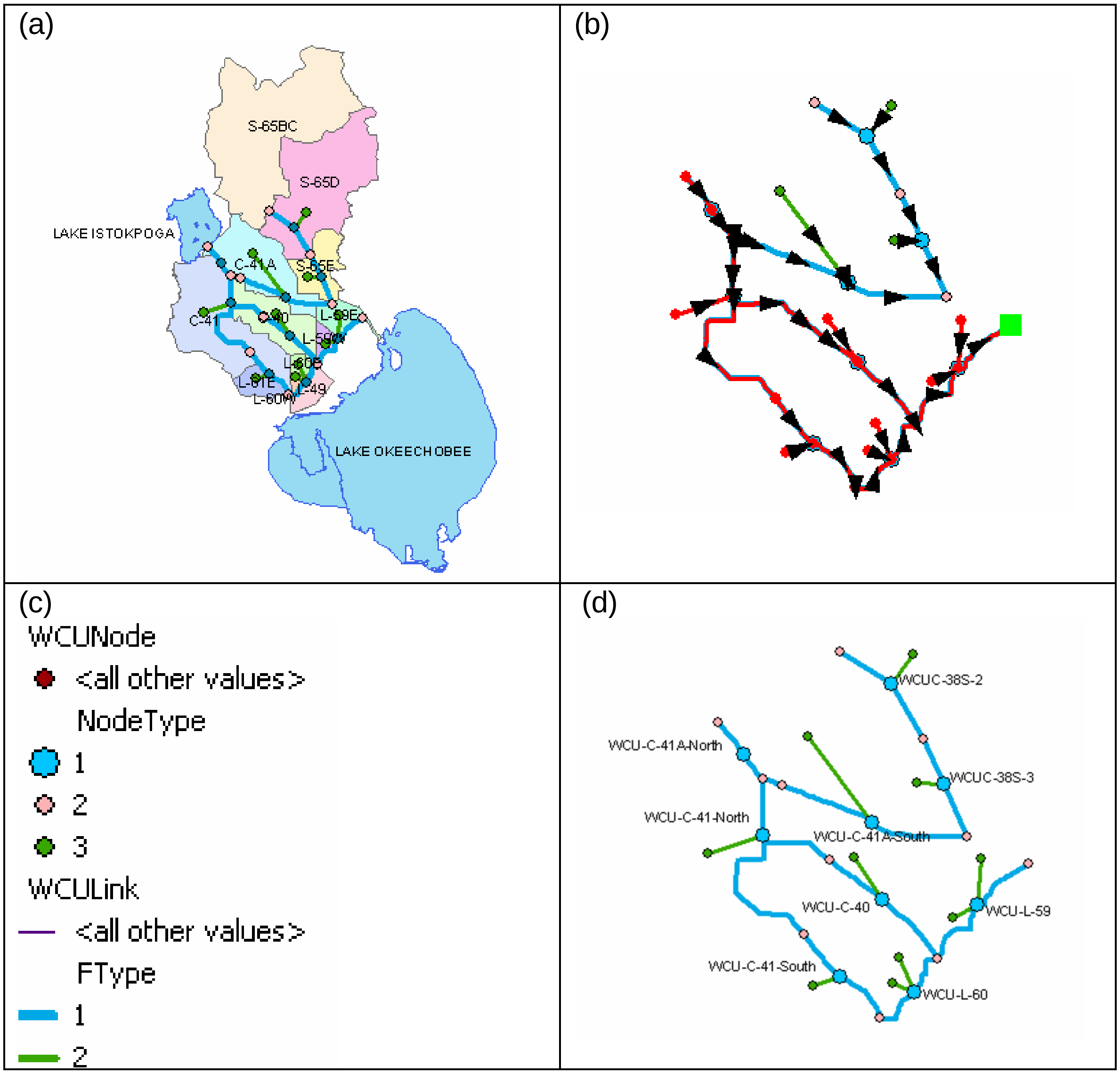


Figure 2.3-7. A prototype of the ODSS extension data model. (a) Location map (b) The water control network showing flow direction and an upstream trace from the outlet of WCU-L-59. (c) Legend showing symbolization of the different types of WCU nodes and links (d) a map of the water control network. Blue dots represent water control units, pink dots are structures, green dots are basins; blue lines are canal segments in the water control units, green lines are connections of the basins to the water control units.

UML for RSM Extension Data Model

The conceptual UML for the RSM extension data model is shown in Figure 2.3-8. It contains five new classes:

- **RSM Schematic Node** – a simple junction feature class that represents key locations not otherwise represented in an RSM model. These include water supply sources such as well fields and water use points such as citrus orchards.

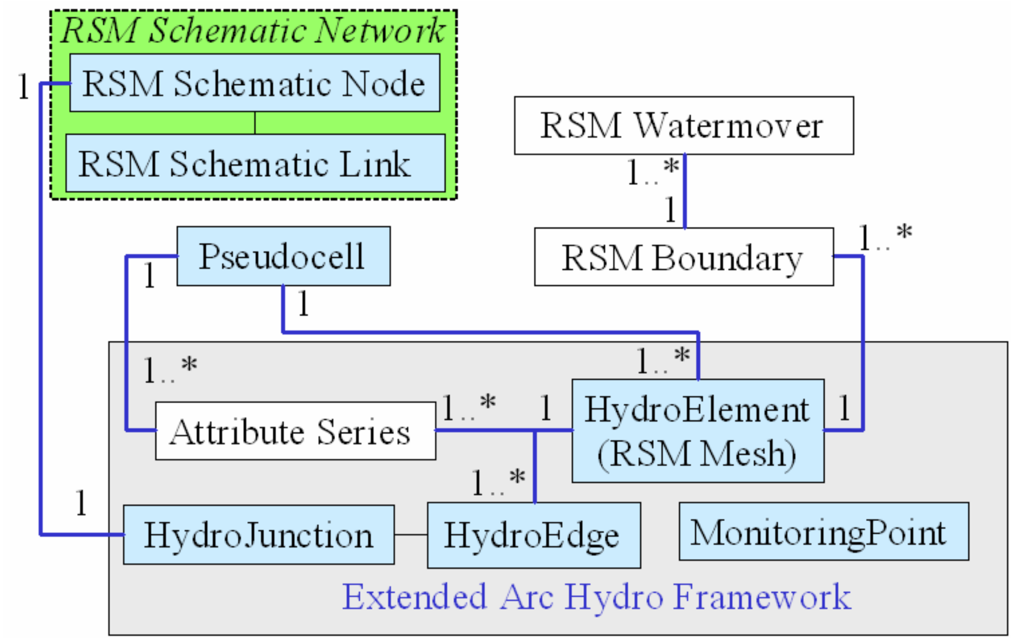
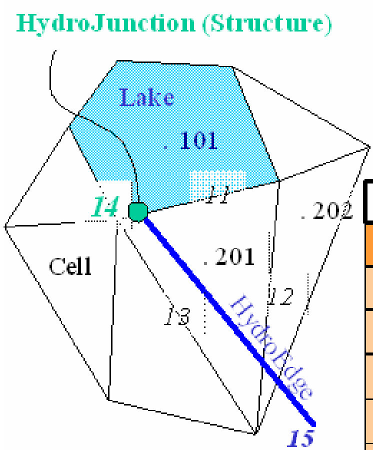


Figure 2.3-8. Extension data model for the Regional Simulation Model



Water Mover Objects

WMvr_Typ	Description
10	Overland Flo
20	GW Seepage
30	Weir
40	Levee Seepag
...	...

Boundary Types

Bnd_Typ	Description
1	Mesh Segment
2	HydroJunction
3	HydroEdge

Boundary Table

Bnd_ID	Bnd_Typ	Obj_ID
1011	1	11
1012	1	12
1013	1	13
1014	2	14
1015	3	15

Water Mover Table

Bnd_ID	WMvr_Typ
1011	10
1011	20
1012	10
1012	20
1014	30
1015	10
1015	20
1015	40

Figure 2.3-9 Definition of RSM boundaries and water movers

- **RSM Schematic Link** – a simple edge feature class that connects RSM Schematic Nodes and permits water movement through the landscape not otherwise represented in the RSM model, such as by a pipeline between a well field and a citrus orchard. The RSM Schematic Node and Link classes are connected in a geometric network.
- **PseudoCell** – a polygon feature class that represents the vertical water balance between the land surface and the atmosphere in RSM
- **RSM Boundary –** an object class that lists the boundaries of RSM mesh cells, canal segments and structures (as shown in Figure 2.3-9).
- **RSM Watermover –** an object class that lists the types of water movers that RSM supports

Figure 2.3-8 shows seven relationships connecting the RSM extension data model classes with themselves and with the enhanced Arc Hydro framework:

- **RSM Schematic Node to HydroJunction** (1 to 1) – links the RSM Schematic Network to the HydroNetwork
- **PseudoCell to HydroElement** (1 to many) – defines HydroElements (RSM Mesh Cells) within a PseudoCell
- **PseudoCell to Attribute Series** (1 to many) – the time series associated with the PseudoCell feature class are stored as Attribute Series

- **HydroElement to HydroEdge** (1 to many) – one HydroEdge such as a canal segment, crosses many HydroElements
- **HydroElement to Attribute Series** (1 to many) – the time series associated with the HydroElement feature class are stored as Attribute Series
- **HydroElement to RSM Boundary** (1 to many) – a HydroElement has several boundary segments
- **RSM Boundary to RSM Watermover** (1 to many) – an RSM Boundary has one or more modes in which water can move through it.

This conceptual design for the RSM extension data model has not benefited from the construction of a prototype as yet, and its structure will be refined as a prototype is developed. It is likely that a more extensive Interface Data Model will be needed to support the RSM model like the ones that have been developed at CRWR for the HEC-HMS, HEC-RAS, Modflow and other hydrologic simulation models.

UML for the Flood Hydrology and Hydraulic (H&H) Extension Data Model

Flood hydrology and hydraulic (H&H) modeling takes place on a smaller spatial domain than that used for ODSS and RSM, typified in this project by the C-4 basin where an XP-SWMM model has been developed to represent flood seepage and water flow (Figure 2.3-10). Flood H&H modeling can also be done with other modeling systems such as those produced by HEC and DHI. These models are all complex systems that differ from one another in the methods they use and in the way they parameterize their model functions. What is represented here is a generic structure intended to support one or other of these models, not a particular structure for an individual model. Individual model connections are made to Arc Hydro using a specially designed Interface Data Model or by using the PBS&J Watershed Analyst, which is a generic approach intended to store parameters for many hydrologic models within a unified data structure.

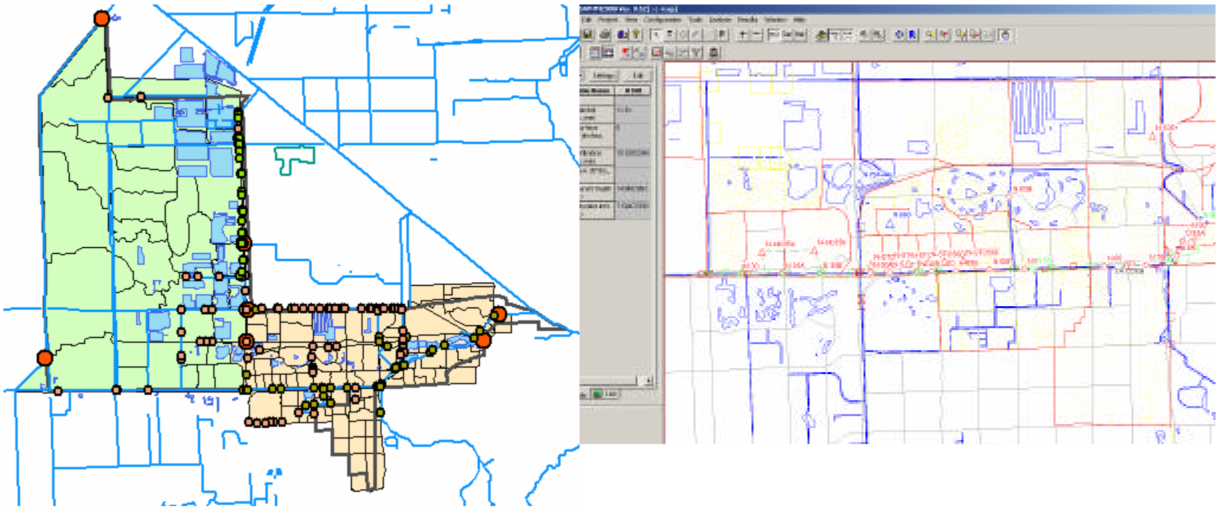


Figure 2.3-10 C-4 Basin and the XP-SWMM model of this basin

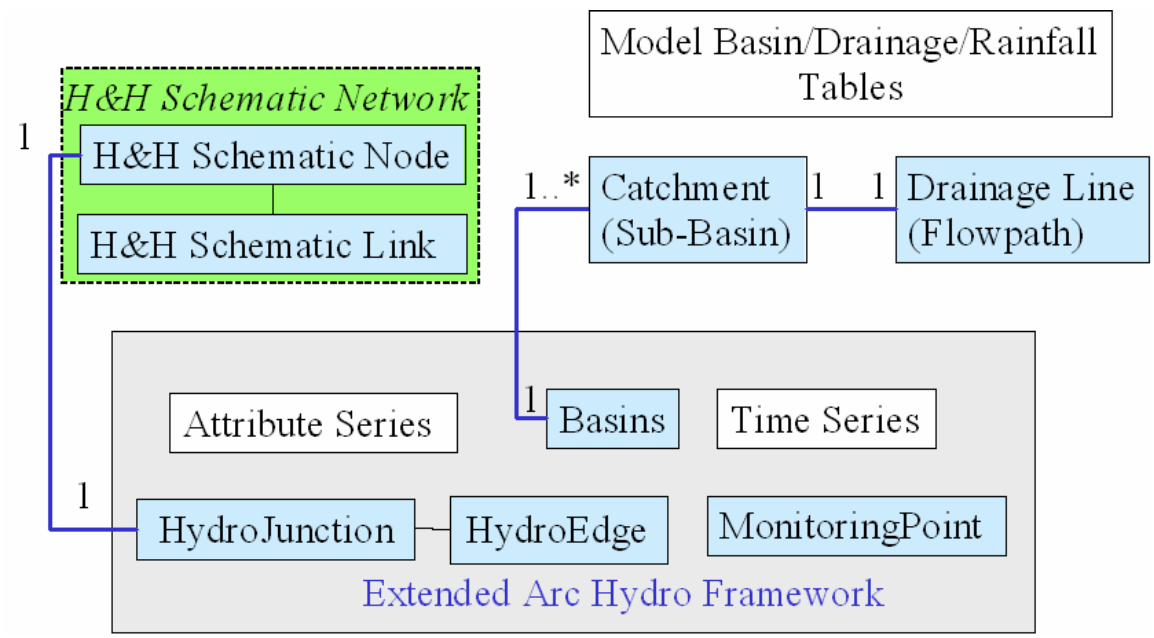


Figure 2.3-11. Extension data model for flood hydrology and hydraulics

The flood hydrology and hydraulic extension data model contains four feature classes (these are all feature classes drawn from the complete Arc Hydro model so no new feature classes are being added here):

- **H&H Schematic Node** – a simple junction feature class used to represent strategic points in an H&H model (sub-basins, confluences, storages)
- **H&H Schematic Link** – a simple edge feature class that connects H&H nodes, that in some cases may represent a structure such as a pumping station

- **Catchment** – a polygon feature class representing small drainage areas
- **DrainageLine** – a line feature class representing a flow path of water movement within a catchment

There are three relationships shown in Figure 2.3-11:

- **H&H Schematic Node to HydroJunction** (1 to 1) – links the H&H Schematic Network to the HydroNetwork
- **Basin to Catchment** (1 to many) – associates a basin with a set of catchments
- **Catchment to DrainageLine** (1 to 1) – defines the main flow path for water movement in a catchment (and thus the length of the longest flow path and the lag time between rainfall and runoff on the catchment)

The Model/Basin/Rainfall Tables box shown in Figure 2.3-11 is intended to represent the model-specific tables needed to support a particular hydrologic or hydraulic model. Linking flood hydrology and hydraulic models to ArcGIS and Arc Hydro is a subject that has been extensively studied in other projects by CRWR and by PBS&J. While little detail is shown here about such things as stream cross-sections for hydraulic modeling, the CRWR-PBS&J team is conscious of the need for these additional features not shown in Figure 2.3-11.

UML for the Hydroperiod Extension Data Model

The definition of Hydroperiod involves a complex array of spatial and temporal analysis of flood inundation patterns. Defining how this task should be carried out has been an illuminating exercise in the larger task of defining a more complete Arc Hydro time series model. As described earlier, this consists of four time series representations: Time Series, Attribute Series, Feature Series and Raster Series (Figure 2.3-12). All of these representations are used in the Hydroperiod extension data model. These time series representations are included in the Enhanced Arc Hydro Framework model rather than in the Hydroperiod extension of that model because it is anticipated that the same concepts will be useful in other business areas, such as in the definition of inundation occurring in flood hydrology and hydraulics or in the RSM model.

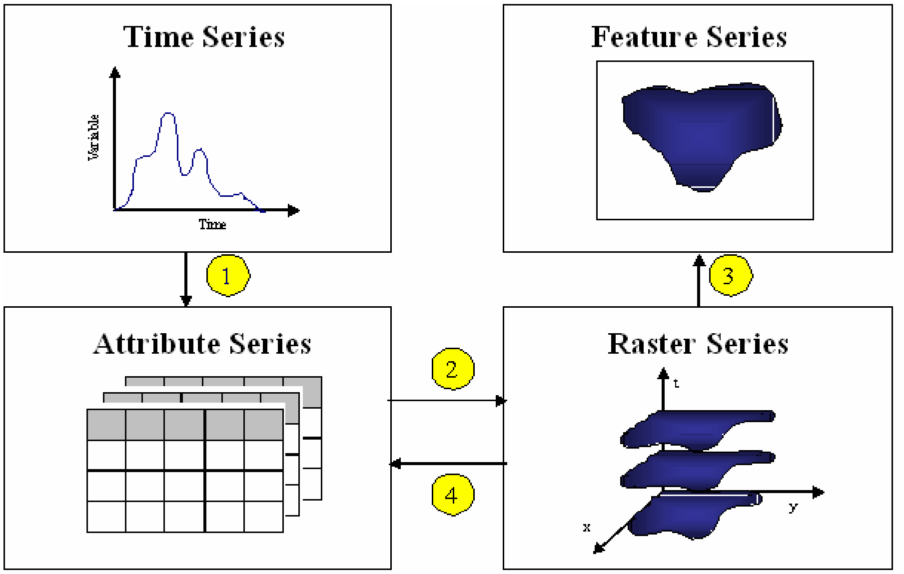


Figure 2.3-12 Representation of time varying information

Figure 2.3.13 presents three new classes in the Hydroperiod extension data model:

- **Land Category** – a polygon feature class defining categories of habitat or land cover whose inundation characteristics are desired
- **Flood inundation region** – a polygon feature class defining a bounding polygon (e.g. 100 year or 500 year flood plain) that is the outer limit for which hydroperiod analysis is needed in a particular area
- **Depth Class** – an object class defining ranges of depths for which inundation characteristics are required.

In addition, DBHydro is shown as an insert in Figure 2.3-13, to represent the location for stage data downloaded from DBHydro that are used in Hydroperiod analysis. These are stored as Arc Hydro time series. There are two relationships shown in Figure 2.3-13:

- **Land Category to Attribute Series** (1 to many) – this connects the time series of inundation characteristics to the land categories being described
- **DBHydro to Time Series** – this connects the DBHydro and Arc Hydro representations of time series (this connection has not been properly defined as yet)

The line connecting Depth Class and Feature Series in Figure 2.3-13 is intended to symbolize the fact that when the raster series of water depths is classified using the Depth Class table, it results in a feature series of water depth polygons for each depth class.

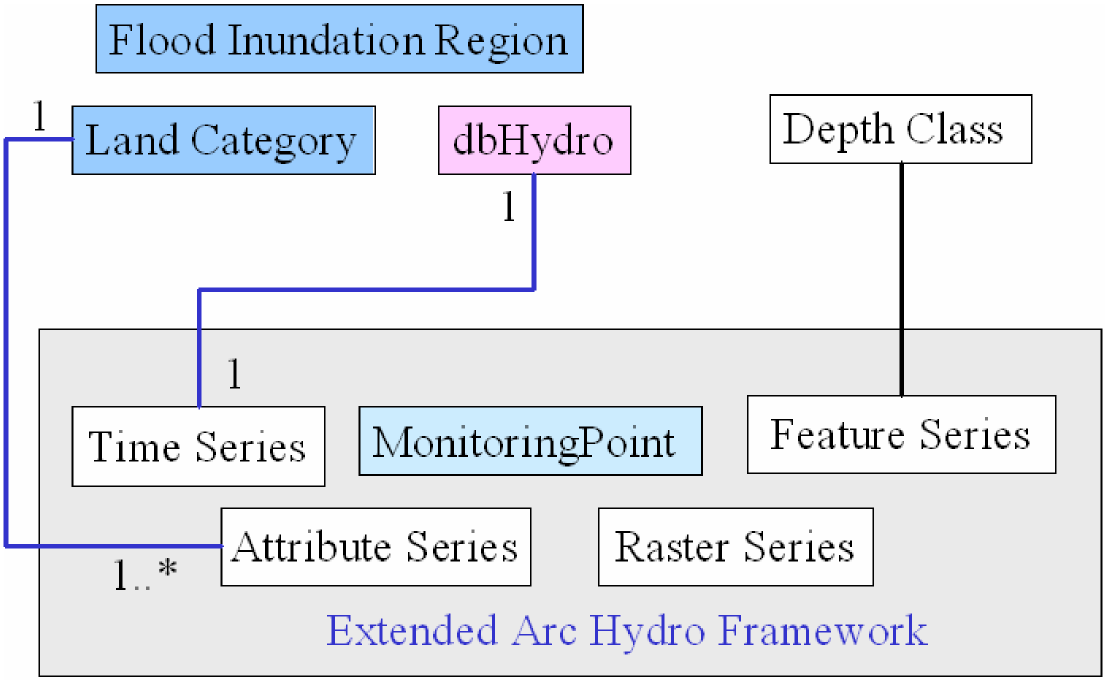


Figure 2.3-13. Extension data model for Hydroperiod estimation

Conclusions

This paper summarizes the understanding arrived at to date as to the form of an enhanced Arc Hydro framework data model and a series of extensions needed to support four business areas in the District who are sharing the framework as their core geospatial data representation. There are two parts to the framework: a *geographic* part that describes the critical physical features of the water environment, and a *hydrologic* part that describes the water conditions occurring within that environment, in time series of various forms. Several features new with ArcGIS version 9 are used here, including the multipatch method for constructing 3-D HydroElements, and the Raster Catalog for storing a series of time-indexed rasters in a geodatabase. The form of time series representation used here is significantly augmented from that used earlier in Arc Hydro.

Defining geographic data models is a process of achieving a common description and nomenclature for representing the geography of the world and the functions that take place on that geography. It has the merit of enable complex functional systems, such as ODSS and RSM to have a common data framework and thus to have the potential to more readily exchange information between these systems.

The conceptual designs presented here will be developed and refined through construction of prototypes for the framework and the ODSS network during Task 2 and for each of the extension models in later phases of this project.

2.4. System Specifications

The Enhanced Arc Hydro Framework will reside in a much larger system that includes all the projects and data maintained by the District. This section presents those relationships and high-level specifications for the interaction of the Enhanced Arc Hydro Framework with the rest of the system.

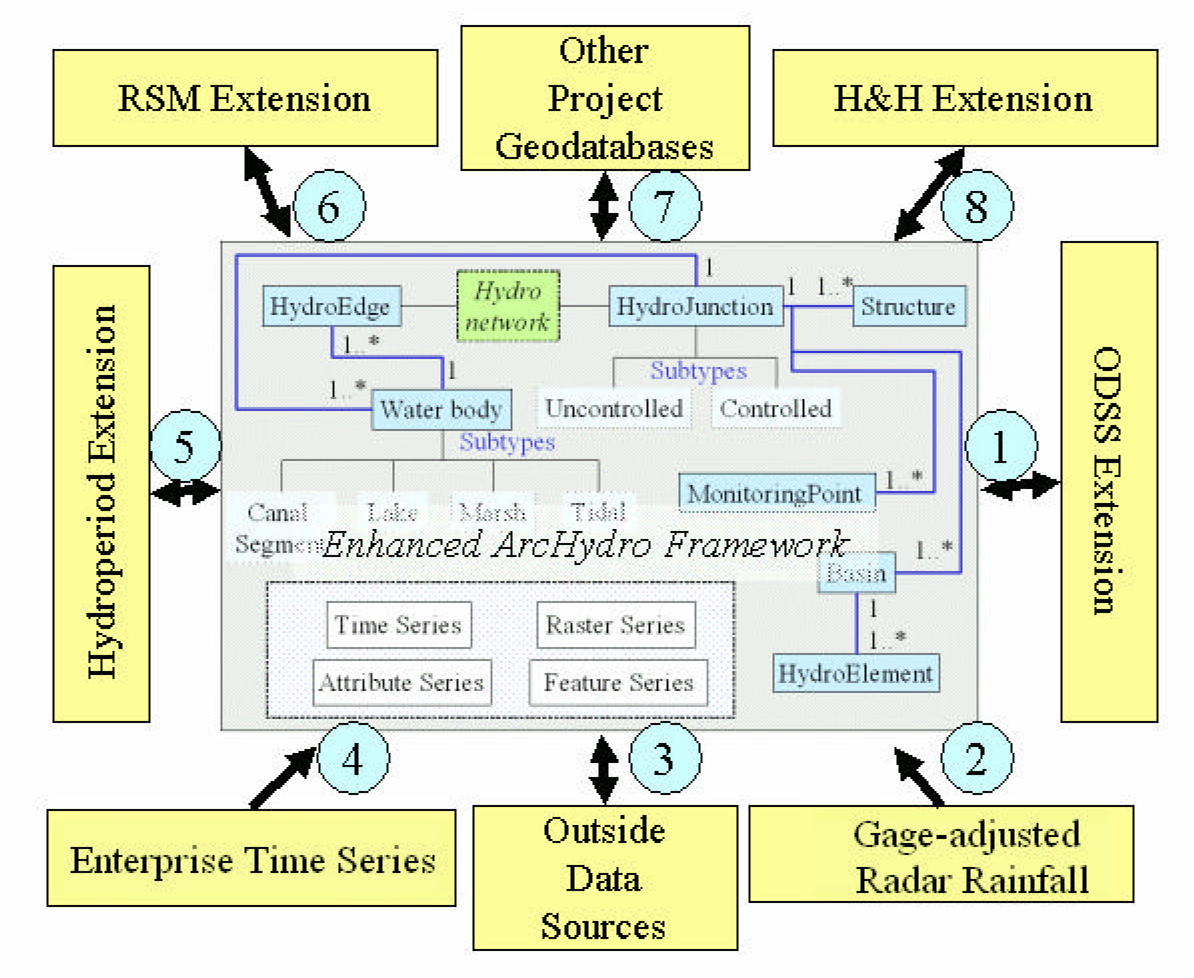


Figure 2.4-1 Enhanced Arc Hydro Framework in the larger System Environment.

Each of the numbered interactions shown in Figure 2.4-1 will require a detailed specification of the interface. Translation tables will be relied on to create executable specifications for all interfaces that require data exchange. Interfaces that simply use data from one side of the interface as input to a process on the other side of the interface will specify both the format and the method for data exchange.

Note that all of the geometric interfaces shown in Figure 2.4-1 can be executed using the standard ArcGIS toolbox. Implementation of tools to automate and standardize the interfaces avoids the repetitive use of tedious detailed steps that would be prone to user error. Implementation of these interfaces will be an ongoing process as the system is used and further needs are identified. The nature of each numbered interface in Figure 2.4-1, and discussion of the implementation, are listed below.

1. The ODSS Extension- The interface is not part of Task 2, but will be specified as part of a separate task. The ODSS framework will be implemented under the Enhanced core Arc Hydro for the Task 2 sample data sets.
2. Gage-adjusted Radar Rainfall data - Task 2 will provide the data structures and specify the interfaces required to import gage-adjusted radar rainfall data and to extract relevant rainfall to a defined geographic area for a defined time period. Actual interface development is a Priority 2 item for Task 2 if budget permits or a related task.
3. Outside Data Sources-Tools for Importing Outside Data for populating the geodatabase, with specifications for assignment of HydroID and for lookup tables to map unique identifiers in the source data to HydroID and HydroCode in Arc Hydro. Priority 1.
4. Enterprise Time Series databases such as DBHydro – Task 2 will provide specifications for the functional requirements and data types to be used through Enhanced Arc Hydro. Further research will be conducted under Task 3 to identify the best method or methods to interface with DBHydro. Two primary options are spatial joins to DBHydro tables by way of a lookup table in Arc Hydro, or import of DBHydro data to Arc Hydro time series. Because DBHydro is too large to import to Arc Hydro in total and it is used by other applications at the district, it is likely that the interface will remain a relational join. However, since project-specific extracts of DBHydro should be stored in the Business Unit Extensions to Arc Hydro, a logical approach would be to provide the ability through Arc Hydro to extract linked DBHydro data into project geodatabases. Task 2 specifications will include studying the feasibility of creating custom Views accessible directly from the DBHydro RDBMS through an ArcHydro Tool developed as a future task.
5. Hydroperiod Extension – The interface between Arc Hydro and the Hydroperiod Extension geodatabase is not part of Task 2. It will be addressed during Task 3.
6. RSM Extension – The interface between RSM or an RSM extension geodatabase and the Expanded Arc Hydro model is not part of Task 2. It will need to be addressed by District staff or through a separate task order.
7. Other Project Geodatabases – The interface between Enhanced Arc Hydro and other project geodatabases will take the form of a geographic extraction of Arc Hydro layers into a local project geodatabase as the foundation for the project. These tools are already part of the ArcGIS library. The advantage of maintaining a project geodatabase built on Arc Hydro is that it provides a snapshot of Arc Hydro at the time of the project.

The Arc Hydro core model will always represent the current state of the system. A simple link to Arc Hydro cannot archive the state of the system at the time of the project. An extract can be archived with the project and will not change. A special case will be projects conducted by data stewards and intended to provide updates to the core Arc Hydro model. In this case, direct editing of the core Arc Hydro or disconnected editing of an extract would be the appropriate measures. Testing and validation of disconnected editing will be conducted during task 2 by the consultant in cooperation with the District.

8. H&H Extension – The requirements of the H&H extension are substantial, with goals including the maintenance in each basin of all GIS data required for detailed flood modeling and for creation of FEMA standard Digital Flood Insurance Rate Maps (DFIRM's). The H&H geodatabase extensions, including model results, will be related to features in Arc Hydro to enable comparisons with other models and with real data, as well as to assist in Watershed Management. Task 2 will provide the data structures and hooks so that the H&H extension and the appropriate interfaces can be implemented under a separate task.

2.5. Implementation Priorities

The following priorities have been identified during Task 1:

2.5.1. **Hydroperiod Tools, to be implemented under Task 3, will require the Enhanced Arc Hydro Geodatabase to provide input data and a format for reporting results.** Because many of the Hydroperiod tool time-series data structures are being incorporated into Enhanced Arc Hydro, or related to Enhanced Arc Hydro features, there is a close synergy in the development of both products. With the completion of a conceptual model for both Hydroperiod and Enhanced Arc Hydro during Task 1, the most effective approach will be to proceed in parallel with Task 2 and Task 3 implementations. Hydroperiod data will be implemented in a combination of the Project geodatabase for Hydroperiod, and will supply standards and sample data to the Enhanced Arc Hydro implementation.

2.5.2. **Operations Decision Support System project database implementation and associated applications.** The need to keep implementation of the ODSS on a fast track indicates a key component of the Enhanced Arc Hydro implementation will be its interactions with ODSS. Because ODSS and its Water Control Units represent a regional framework on which all the other projects can build, ODSS data will be key in the initial implementation of Enhanced Arc Hydro. Frameworks will be built for Okeechobee, for a selected region to be provided by the RSM team where an RSM model is available, for a representative portion of the C-4 Basin as a foundation framework for H&H modeling, and for a representative portion of the Kissimmee River as a foundation framework for Hydroperiod analysis. The data model for ODSS Extension to Enhanced ArcHydro will be proceeding in parallel under a separate task to design the ODSS project geodatabase and interface to Arc Hydro. Insights and modifications from the ODSS project geodatabase implementation will be shared with the Task 2. Enhanced Arc Hydro.

2.5.3. **Hydrology and Hydraulics (characterized by the C-4 Basin) has an immediate need to build a detailed, FEMA-compatible geodatabase for storing all model data and results for each basin.** In order to accommodate this need, a geodatabase design for storing hydrologic and hydraulic modeling data in GIS will be implemented under a separate task order. Task 2 implementation will use data from C-4 to populate the Enhanced Arc Hydro geodatabase and will incorporate any insights gained from the project geodatabase implementation.

2.5.4. **The sample RSM model to be provided by the RSM team will provide sample data for populating the Enhanced ArcHydro framework in the region of that model, and a test bed for building interactive capabilities between RSM and Enhanced Arc Hydro during as part of a future task.**

2.6. Future Modifications and Enhancements

Because of the fast-track requirements of Hydroperiod Tools, ODSS project – specific geodatabase design, and Flood Mitigation FEMA-compatible geodatabase design, many potentially “future” modifications and enhancements will be taking place in parallel with Task 2 implementation of the Enhanced Arc Hydro geodatabase and interface tools will be developed under these separate, parallel task orders.

RSM Model interaction with the Enhanced Arc Hydro geodatabase will be limited during Task 2 to building data structures to store data commonly used by RSM and the other projects, and to accommodate results from RSM modeling runs. An important future modification will be to integrate RSM with Enhanced Arc Hydro by building interfaces and tools. Key tools to automate loading data from Enhanced Arc Hydro into RSM and to return results from RSM to Enhanced Arc Hydro, will greatly increase the ability to easily share RSM data with other projects and compare RSM results with other models.

Appendix A - Glossary

Arc Hydro- An ArcGIS-based system geared to support water resources applications. It consists of two key components:

- · Arc Hydro Data Model
- · Arc Hydro Tools

These two components, together with the generic programming framework, provide basic database design and a set of tools that facilitate analyses often performed in the water resources area. Arc Hydro is intended to provide the initial functionality that can then be expanded by adding to it database structures and functions required by a specific task or application.

Arc Hydro Data Model- The comprehensive data model for Hydrology developed by the GIS in Water Resources Consortium, led by Dr. David Maidment. Five major components of the data model are 1) Drainage features, including basins; 2) the "HydroNetwork" – a connected set of points and lines showing the pathways of water flow in conveyance ways; 3) Hydrography including "hydroresponse units" (defined below); 4) Channel features including Reach codes, profiles and cross-sections; and 5) Timeseries to store time-varying attributes such as water surface elevation or flow for any hydro feature.

Arc Hydro Framework Data Model- The framework is a subset of the complete Arc Hydro data model. It stores only the key information related to hydrography (physical environmental setting) and hydrology (the hydrologic cycle in the watershed). It includes data describing rivers, canal networks, watersheds, water bodies, and monitoring points. Additional components can be added to the basic framework to describe a more complex environmental/hydrologic setting.

Arc Hydro Tools- The Arc Hydro tools are a set of utilities developed on top of the Arc Hydro data model. The tools have two key purposes. The first purpose is to manipulate (assign) key attributes in the Arc Hydro data model. These attributes form the basis for further analyses. They include the key identifiers (such as HydroID, DrainID, NextDownID, etc.) and the measure attributes (such as LengthDown). The second purpose for the tools is to provide some core functionality often used in water resources applications. This includes DEM-based watershed delineation, network generation, and attribute-based tracing.

Arc Hydro Waterbody- An areal water feature. A waterbody may contain many HydroArea polygons depicting detail, such as islands within a water body.

ArcSDE- ArcSDE is a gateway that facilitates managing ESRI spatial data in a relational database management system. ArcSDE allows you to manage geographic information in one of four commercial databases: IBM DB2, IBM Informix, Microsoft SQL Server, and Oracle, as well as being able to serve ESRI's file-based data with ArcSDE for Coverages. ArcSDE serves spatial data to the ArcGIS Desktop (ArcView, ArcEditor, and ArcInfo) and through ArcIMS, as well as other applications and it is the key component in managing a multi-user spatial database.

Basin- NOTE – Tentative agreement was reached 11/17/2003 to adopt the standard Arc Hydro terminology at SFWMD (in accordance with National Hydrography Network standards). What are currently called Basins at SFWMD will be referred to as watersheds.

1. **SFWMD terminology-** Basins are derived from a tessellation or subdivision of a regional watershed into a drainage area selected for a particular hydrologic purpose. Basins may drain to points on a river network, to river segments, or to water bodies. Equivalent to *Arc Hydro Watershed.*
2. **Arc Hydro terminology-** the meaning of Basin and Watershed is reversed between Arc Hydro and common practice in Florida Water Management Districts. In Florida Water Management Districts and many regions up the East Coast, Watersheds are regional drainage areas (e.g. Chesapeake Watershed) from which basins and sub-basins are divided. In Arc Hydro, basins are regional drainage areas (common in Western U.S. e.g. Rio Grande Basin) from which Arc Hydro Watersheds and Catchments are subdivided.

Sub-Basin (Arc Hydro Catchments)- A tessellation or subdivision of a basin into elementary drainage areas defined by a consistent set of physical rules.

C-4- The C-4 Basin is located within Miami-Dade County of South Florida.

CERP (Comprehensive Everglades Restoration Plan)-
CERP Zone – The shared information network constructed to support the CERP under the guidance of CERP Program Controls.

Channel- A river or stream conduit or water course carrying water flow under gravity. The water-surface profile is sloping and the flow has a significant velocity. The width of the channel is much smaller than its length, and the flow is essentially one-dimensional in the direction of the channel centerline. The channel includes the flow in the main channel of the river or stream itself and also in its floodplains to the left and right of the main channel. The channel is like a “cradle” that carries the flow. It has a complex three-dimensional geometry and additional properties such as channel roughness. Examples of hydrographic features having channels are river, stream, creek, canal, ditch, culvert, and storm sewer.

Conceptual Data Model- Used to identify concepts and the relationships between them.

Cross Section- A transverse profile of a stream or river channel represented by a line drawn through the base of the channel perpendicular to the direction of flow

Drainage feature- A point, line, or area feature contained within the drainage system of the landscape. Represented in the data model by an abstract class carrying attributes common to all drainage features

EPA-SWMM- Environmental Protection Agency- Storm Water Management Model. A public domain set of integrated hydrologic, hydraulic and water quality models used to model the full hydrologic cycle from stormwater & wastewater flow, pollution generation, to simulation of the closed conduits with any boundary conditions.

Geodatabase- A collection of geospatial data stored in a relational database format.

Hydraulic Head- The height of the free surface of a body of water above a given point beneath the surface. (2) The height of the water level at the headworks, or an upstream point, of a waterway, and the water surface at a given point downstream. (3) The height of a hydraulic grade line above the center line of a pressure pipe, at a given point.

Heads and Flows- Short for **Hydraulic Heads and Flows.** Refers to measurements and/or model results that indicate the hydraulic pressure of a volume of water by measuring the difference in water surface elevations between two surface points (typically across a boundary) or the difference between the water surface elevation and a subsurface boundary. Flows of water resulting from the head difference are typically measured in velocity (e.g. Feet/second) and converted to volume versus time (e.g. cfs - cubic feet / second). Conversion is done by knowing the cross-sectional area of the water volume at the measuring point. Typically the heads and flows from a hydraulic model are compared to monitored heads and flows from stream gages in order to calibrate the model.

HEC- U.S. Army Corps of Engineers Hydrologic Engineering Center

HEC-HMS- HEC Hydrologic Modeling System – the hydrologic component (runoff resulting from rainfall over a watershed) of the HEC modeling system.

HEC-RAS- HEC River Analysis System – the hydraulic component of the HEC modeling system – 1-D steady and unsteady flow in open channels and associated water surface elevations.

Hydrograph- A graph showing the water level (stage), discharge, or other property of a river volume with respect to time.

Hydrologic Budget- An accounting of the inflow to, outflow from, and storage in, a hydrologic unit, such as a drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project.

Hyetograph- A graphical representation of rainfall intensity with respect to time.

Overland Flow- The flow of rainwater or snowmelt over the land surface toward stream channels. After it enters a watercourse it becomes runoff.

Parametric Data- Data such as rating curves, unit hydrographs, and rainfall/runoff curves which define hydrologic variables in models.

Pool Height- The height of the water behind a dam. (Various datums may be used and various pool height may be used, e.g., conservation pool, flood control pool, etc.)

Weir- (a) A low dam built across a stream to raise the upstream water level (fixed-crest weir when uncontrolled).

Hydroperiod- The length of one wet and dry cycle. For non-tidal wetlands, the average duration of flooding, which is based only on the presence of surface water and not its depth.

Hydro Edge- A simple or complex edge- feature representing a line in the hydro network

Hydrography- An abstract class carrying attributes of hydrography features. In general, hydrography contains the “blue lines” on maps and point features created from tabular data inventories.

Hydrology- A study of the water cycle

Hydraulics- Study of how water moves

Hydro Junction- A hydro network junction that is a point of strategic hydrologic interest, such as the outlet of a water body or watershed.

Hydro Network- A geometric network tracing water movement through streams, rivers, and waterbodies.

Hydropattern- A depiction of water levels through annual cycles; this includes water depth and duration, along with quantity, timing and distribution of surface water to a specific area

Hydro Response Units (RSM PseudoCells)- A set of polygons having representative properties for partitioning precipitation into evaporation, infiltration, and runoff at the land surface.

Kissimmee River Restoration (KRR)- The project will restore over 40 square miles of river/floodplain ecosystem including 43 miles of meandering river channel and 27,000 acres of wetlands.

Metadata- or "data about data" describe the content, quality, condition, and other characteristics of data. The Federal Geographic Data Committee approved the Content Standard for Digital Geospatial Metadata (FGDC-STD-001-1998) in June 1998.

Monitoring Points- A permanent monitoring site, such as a stream gauge, rain gauge, or climate station, or a sampling point on a stream or river where water quality samples are taken periodically.

Operations Decision Support System (ODSS)- The purpose of ODSS is the provision of Flood Control, Water Supply for Agriculture, Urban, and Everglades National Park uses, Prevention of Saltwater Intrusion, Navigation, and Protection of “fish and wildlife”.

Regional Simulation Model (RSM)- A tool to be used to predict the affect of implementing physical and operational water management alternatives in the SFWMD network of rivers, canals, and control structures, etc. RSM is currently being developed using object-oriented methodology similar to that of Arc Hydro.

RSM Mesh- A mesh of triangular network elements depicting drainage areas contributing flow from the land surface to the water system and irregular elements bounded by triangular cells depicting lakes. Triangular cells are hydrologic units with three boundaries and a fixed elevation for modeling purposes. Because they have a fixed elevation, rather than a different elevation at each corner, RSM Mesh triangles should not be regarded as equivalent to triangles in a standard TIN model (Triangulated Irregular Network) used represent the ground surface.

SDE – See ArcSDE

Schematic Link- A line in a schematic network connecting hydro features.

Schematic Node- A point in a schematic network connecting hydro features.

Watershed- See Basin

Water Balance- An accounting of the inflow to, outflow from, and storage in, a hydrologic unit, such as a drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project (also Hydrologic Budget).

XP-SWMM- A commercial adaptation of the SWMM models with a graphical user interface. Used to model the full hydrologic cycle from stormwater & wastewater flow, pollution generation, to simulation of the closed conduits with any boundary conditions.

Appendix B – Details of the Four Concept Projects

B.1 INTRODUCTION

This section provides a general description of the minutes of the 2-day project kick-off where each of the four concept projects for the Enhanced Arc Hydro Framework presented project overviews. The narrative was created from handouts provided by presenters and from notes collected by PBS&J staff.

Two days of presentation were featured at the project meeting kick off held on August 19 and 20, 2003, at the South Florida Water Management District (SFWMD) West Palm Beach headquarters. The purpose of the kick off meeting was to discuss the proposed work plan, as originally proposed by PBS&J, and to adjust information to be presented by key stakeholders of the District's technical staff at the Charrette meetings to be held in September. During the first day of the kick off meeting, attendees (See attached list) listened to an introductory presentation by Dr. David Maidment related to the Arc Hydro methodology. Dr. Maidment was followed by presentations from representatives of two of the four (4) concept projects: Chris Carlson presented the Hydroperiod Estimation Tool requirements, and Randy Van Zee presented the Regional Simulation Model (RSM) components and technical specifications. In the morning of the second day of the meeting, Dr. Ken Konyha presented the flood-control related issues of the District, and Dr. Ken Stewart addressed the operational characteristics of the Operations Decision Support System of the SFWMD. In the afternoon of the second day, Dr. Maidment summarized his understanding of the upcoming effort in the context of the four concept projects presentations, and PBS&J closed the meeting with a presentation of the upcoming Charrette meetings.

B.2 HYDROPERIOD ESTIMATION TOOL (By Chris Carlson)

Ms. Carlson, a senior scientist with the Kissimmee River Restoration Division, addressed the components of the required Hydroperiod Estimation Tool. The definition of "hydroperiod" was postponed until the Charrette, and the word hydroperiod was associated in the presentation with accumulation of water depth at a landscape unit and as a function of time.

Hydroperiod Estimation Tool components

- Input parameters
- Statistical Interpolation
- Data analysis and output

Input parameters

Ms. Carlson indicated that input parameters need to be specified by geographic extent and/or selected *landscape unit.* The unit type, size, and location need to be an item of discussion at the Charrette meetings.

Topographic data sets need to include topography and vegetative communities. The number of stations and locations and their sensitivity to desired results should be addressed in the context of the selected landscape unit. The issue of “cell inclusion”, during the process of landscape unit selection, merits careful consideration to arrive at a suitable “masking procedure” or rule.

A period of analysis (POA) must be defined to apply the proposed Hydroperiod Estimation Tool. This period must be consistent with the stage recorder network period of data availability, to data aggregation during this period, and to an identifiable landscape unit of analysis.

Statistical interpolation

Ms. Carlson stated that statistical interpolation will be performed for water levels above the surface only at this time. Levels below the surface will be addressed later during a future phase of the project. Water surface elevations (WSE) will be estimated using observed data available through DBHYDRO. WSE’s from stage recorders must be linked to landscape features.

Stage recorders should be selected at the time a geographic area and a landscape unit(s) is defined for the project. Stage recorder coverage could be extended to “soft” stations using “Kriging” techniques associated with three-dimensional digital elevation (spatial) modeling, between observed WSE’s and stage recorder WSE’s.

Data analysis/output

Ms. Carlson indicated that data analysis needs to be performed in the context of time series graphs and maps (ArcGIS time-index grids). Statistical and geo-statistical techniques will be performed for the selected landscape unit data. Spatial and temporal autocorrelation issues as well as uncertainty analysis will be performed to arrive at tabular data output sets of desired probability of occurrence and accuracy.

B.3 REGIONAL SIMULATION MODEL – RSM (By Randy Van Zee)

Randy Van Zee, chief hydraulic modeler with the Hydrologic Systems Modeling Division (HSM), presented the Regional System Model (RSM). The goal of RSM is to simulate the hydrology and manmade water control features of South Florida. The RSM will be used to predict the consequences of implementing physical and operational alternatives designed to address changing water management priorities and issues. This model represents the next generation of integrated water management modeling and grasps the complexity available and necessary to support decision-making processes well into the 21st Century. This model is currently 'under development'. Individual components are being developed independently and are in various stages of completion.

The RSM has been designated as a replacement of the existing 2 mile by 2 mile South Florida Water Management District Model. The South Florida Water Management Model (SFWMM) was developed during the late 1970s and early 1980s and has served as the primary regional simulation model in south Florida for nearly two decades. New initiatives such as Everglades Restoration and Water Supply Planning have placed new demands for information from regional simulation models. The RSM will be the next generation SFWMM that will be developed using recent advances in computer technology, in particular, GIS, Databases, and Object-Oriented model development. The new RSM will also make use of the more realistic, accurate and efficient numerical algorithms to simulate hydrology and water management in South Florida using a variable mesh structure. It is expected that the RSM will eventually replace the existing SFWMM, and years of development and testing will be needed before RSM becomes fully operational for the entire system.

Model Overview and Historical Perspective

- Development initiated in 1993
- "Next generation" South Florida Water Management Model (SFWMM)
- Unique class of models
- Regional in scale
- Long term simulation periods (30+ years)
- Complex hydrology
- Complex management

Overall Design Objectives

- Develop tool suitable for analyzing future water management alternatives
- Combine state of the art science with advanced software engineering
- Broaden user and developer base

Application Objectives

- Retain SFWMM capabilities
- Adaptable to local and regional scales
- Easy to use, flexible and robust
- Supported by peripheral tools, e.g. GUI, Databases, GIS, auto-calibration

Development Objectives

- Easy to maintain and modify
- Minimize "single-person" dependency
- Use state of the art technology
- Provide extensive documentation

Design Choices

- **Object-Oriented principles**
- C++ programming language
- Parallel development efforts
- *Hydrologic Simulation Engine (HSE)*
- *Management Simulation Engine (MSE)*

Hydrologic Simulation Engine "HSE"

- Simulates hydrologic processes
- *2D horizontal flow (surface & groundwater)*
- *1D canal network flow*
- *2D and 1D flow interactions*
- *Local hydrology*

Principle HSE Components

- "Water body" object
  Holds water, e.g. cell, canal segment, lake
- "Water mover" object
  Conveys water between water bodies
- "Pseudocell" object
  Simulates local hydrology
- *Implemented as boundary conditions to designated water bodies*

HSE Matrix

- Superposition principle
- Simultaneous solution
- *Surface / groundwater*
- *Canal network*
- *Interactions*
- Extensible
- *"Water body"*
- *"Water mover"*

HSE Mesh

- **Management Simulation Engine "*MSE*"**
- Simulates management and control of regional system
- *Assesses flood control and water supply needs*
- *Implements* policies
- Environmental protection
- Balance competing needs
- Flood protection
- *Specifies controllers*

Building an RSM Application

- Water Bodies
- *Mesh – defines cells and pseudocells (GMS)*
- *Network – defines segments (GMS)*
- *Lakes (XML)*
- Default Water Movers – based on geometry
- *"Walls" - 2D surface and ground water*
- *"Junctions" – 1D canal flow*
- *"Streambanks" – cell to segment interactions*

Building an RSM Application

- User defined water movers
- *Boundary conditions (XML)*
- Head, general head, uniform flow, well
- *Structures (XML)*
- Weirs, culverts, lookup tables, bleeders, etc.
- *Lake seepage (XML)*
- *Pseudocells*
- Indexed entry (GMS)
- Specifications (XML)

B.4 BASIN FLOOD CONTROL MANAGEMENT (By Dr. Ken Konyha)

Dr. Ken Konyha, Lead Engineer with the SFWMD's Lower West Coast Division, presented the flood control and mapping issues of hydrologic and hydraulic modeling. Dr. Konyha indicated that flood control needs to be organized spatially by watershed/drainage basin consistent if possible with adjacent water management districts. Within each basin, flood control needs to be organized by function. The Southwest Florida Water Management District (SWFWMD) has already attempted this functional basin organization and a similar approach can be applied at the SFWMD. It is expected that some, if not all geo-spatial information within a basin could be accessed via Arc Hydro.

Arc Hydro should maintain consistent sub-basin and stream network terminology conceptualization: Sub-basins for hydrology and Network for hydraulics. System should accommodate a variety of methods for estimating sub-basin hydrology:

- CN method
- Coupled GW-SW models
- RSM pseudo-cell hydrology
- Local water management district
- Permits and regulation

Global porosity function for each basin is a desirable feature of the Arc Hydro tool. Topography, local detention and pre-storm water levels (AMC's) can be addressed by

Arc Hydro through the use of the global porosity parameter (includes all storage, groundwater, detention storage, overland flooding characteristics).

The SFWMD is going to need several matching sets of sub-basin and stream network information for a designated area (i.e. local scale, watershed scale and regional-scale). It is expected that Arc Hydro will facilitate the generation of these data sets from a uniquely designated (or coded) underlying set of data.

A partial list of H&H modeling required elements include:

- Regional hydraulic (flow and stage) controllers associated with: pump-filled reservoirs, diversion pumps, pump-filled regional detention and water quality treatment areas, etc.
- Local or sub-basin level hydrologic controllers associated with: gates, detention ponds, pumped drainage, pre-storm drawdown, impervious areas, etc.
- Operation rules for: semi-autonomous operations (tide gates); basin-scale rule coordination (such as for detention basin and city drainage pumps); choice of rule set (such as for high flow, dry season, wet season).

The SFWMD already has more than two models that support the same project. For this reason, the Arc Hydro data model and tool should be designed to support at least two models with one database. (Example: coupled surface/groundwater MODNET and conventional flood SWMM H&H models for C-4 project).

The Arc Hydro database will need to be created for two levels of detail: a coarse-scale (few lumped sub-basin areas as used for regional planning and management level models), and a fine-scale (many sub-basins such as for Miami-Dade DERM operational secondary system-based storm water management model).

Generalized Needs for Basin Flood Control

The following list is a draft of information needed for basin flood control management as arranged by SWFWMD watershed management organization and terminology:

1. Digital Topographic Information
    - Digital Terrain Model
2. Watershed Evaluation
    - Water Resource Inventory
    - Watershed Parameterization
        i. Hydraulics - flow paths, control points, infrastructure inventory, storage, conveyance features, …
        ii. Sub-basin hydrology - boundaries, runoff characteristics, BMPs …
    - Immediate Maintenance Evaluation
3. Watershed Management Plan
    - Stormwater Infrastructure Survey
    - Floodplain Analysis
    - Preparation of FEMA FIRM Panel
    - Level of Service Determinations
    - Alternative Analysis of Management Projects
      [CERP, Flood Mitigation, BMPs]

4. Implementation of Selected Management Projects
   Project A
   - Design and Permitting
   - Land Acquisition
   - Construction
   - Operation & Maintenance

   Project B
   Project C
   …
5. Watershed Database Maintenance
   - Watershed Parameters
   - Digital Data Storage
   - Model Update
   - Floodplain Mapping

The ARC-HYDRO Tools to be developed for Flood Control in the South Florida Water management District jurisdiction shall consider:

The coupling of basin delineation with hydrography. Although this SOW focuses on basin scale modeling, flood control planning occurs at three scales: regional (flood operations and management), basin (C&SF Project Design Basins), and local. Certain characteristics must be compatible across all scales: 1) stage-storage relationships, 2) discharge over time, and 3) mass balances of water.

Suitability documentation of the data source and data quality is essential and should be incorporated into the structure of the ARC_HYDRO database. Data quality can be defined in terms of its suitability for specific applications. (Example, topography may be good enough to define basin boundaries but not to define flood plain locations or as in topography being acceptable for a USACE PIR but not for a USACE GRR)

Basin-Scale Spatial Data Requirements

Topographic data
- Digital Terrain Model
  Stage-storage relationships
- Hydraulic data
  Hydrography [matched with sub-basins]
  Inventory of hydraulic features
  Conveyance features (cross-sections, channel parameters)
  Structure data (pumps, culverts, weirs, stop-log risers)
  Operating Rules for Structures
- Hydrologic data
  Sub-basin boundaries [matched with hydrography]
  Runoff characteristics (land use, soil classification, slope)

Time-varying data (non-inclusive)
- Rainfall (may vary over space and time)
- Evaporation (may vary over space and time)

Calibration data

- Measured Rainfall (can vary over space and time)
- Measured Evapotranspiration (can vary over space and time)
- Initial ground water elevations
- Initial stream levels
- Flow data
- Operation logs

Simulation data
- Design Event Rainfall
- Design Event Evapotranspiration
- Initial ground water elevations
- Initial stream levels
- Operation Rules

Background on the C-4 Basin

Dr. Konyha addressed a potential concept project located in Miami-Dade County. The 155 drainage basins within the SFWMD jurisdictional boundaries are composed of a wide variety of hydrologic and hydraulic parameters and characteristics, including both natural and man-made features. *The C-4 Basin, located within Miami-Dade County of South Florida, is an ideal selection to create a pilot Arc Hydro database that is representative of many SFWMD basin features.* Although no single basin is likely to encompass every single feature required within the designed database, the C-4 basin contains many of the features and is representative of an area with real flood problems that are currently in the process of being addressed.

The C-4 basin is subject to frequent flooding during heavy rainfall. There are a number of completed, on-going and planned construction projects in the area to help alleviate at least some of the flooding, including the following:

SFWMD Construction and Implementation Projects

Completed projects:
- S-25B forward pump station (600 cfs)
- S-26 Forward Pump Station (600 cfs)
- Sweetwater Berm (min. elev. 9.00' NGVD) from Turnpike to 107th Ave.

On going projects:
- Emergency Detention Basin Phase I
- Earthwork: completion by October 2003
- G-420 Inflow Pump Station and G-421 Outflow control structure: completion August 2003

Future Projects (approved and under design):
- Emergency Detention Basin Phase II

- Earthwork: target completion May 2004
- G-422 Inflow Pump Station and G-423 Interbasin Transfer Structure: target completion May 2004
- Sweetwater Berm from 107th to 97th Ave.: target completion by April 2004
- C-4 Dredging (Turnpike to 132nd Ave.): target completion by April 2004
- C-4 Dredging (Palmetto to Maul Lake): target completion by April 2004

Future Projects (not approved as of 4/21/04):
- C-4 Dredging between S-25B and Miami River: preliminary estimated completion date: June 2004
- C-3 Improvements: preliminary estimated completion date; June 2004
- G-93 improvements: preliminary estimated completion date: June 2004

Other Projects:
- Local flood protection efforts, such as proposed pumping systems of Sweetwater, Flagami, & Belin
- CERP structures in the major canals, such as S-380 and the proposed C4 / C2 well-field recharge diversion structure
- Large-scale conveyance improvements in the secondary canal network like the C2extension - Pennsuco canal improvements and the C2extension canal improvements
- Large-scale control structures in secondary canals like the structures at C2extension and Northline canal

Existing / Planned Modeling Efforts in the C-4 Basin include:

Ongoing
- Stormwater Master Plan (County, PBS&J, XP SWMM 2000 ver 8.05)
- Increased Pumping Impact Analysis (SFWMD, PBS&J, XP SWMM)

Completed
- C-4 Basin Study - S25B Operational Plan (SFWMD, MODNET)
- Capacity Analysis (SFWMD, PBS&J, XP SWMM 2000 ver 8.01)
- S25B/S26 F. Pumping D/S Effects (SFWMD, PBS&J, HEC-RAS)

Planned
- C-4 GRR (USACE, model to be determined)
- Miami-Dade County Regional Canal Study (USACE/SFWMD, model to be determined)

There are data and information available for the C-4 basin from both the SFWMD and the Miami-Dade County related to the above projects. PBS&J is working with both the SFWMD and the Miami-Dade County on past and current modeling efforts within the C-4 basin to support many of the above listed projects and modeling efforts. PBS&J should therefore have direct access to all available information, either in-house or from SFWMD and County contacts.

B.5 OPERATIONS DECISION SUPPORT SYSTEM - ODSS

Existing Water Management System Infrastructure and ODSS System (By Ron Mierau)

Ron Mierau, the District's Water Control Operations manager presented the components of the SFWND ODSS and its current operational characteristics.

The "Project Purpose" of ODSS is the provision of Flood Control, Water Supply for Agriculture, Urban, and Everglades National Park uses, Prevention of Saltwater Intrusion, Navigation, and Protection of "fish and wildlife".

Water Management System Components
- ~1,800 miles of canals and levees
- 160 major drainage basins
- 200 major structures
- 70 critical (remote automation)
- 130 manual operations
- 27 pump stations
- 6 under remote automation/control

Data Aggregation & Classification
- Parameters (State Estimators)
- Scada/Structure Status
- Site Specific State Variables
- Generalized State Variables
- Water Control Units
- Skeleton of a Watershed
- Aggregate of water bodies controlled as a single unit

Decision Support System Architecture
- Independent of SCADA and Data Acquisition Systems
- Integration of Data Sources through Relational Data Base Management System (RDBMS)
- Current Linkage to SCADA command set and RDBMS through UNIX sockets
- X-Windows Displays
- Coded in LISP (public domain) & C

Graphical User Interface
- Provide Decision Support
- Provide Operator Interface
- Provide Documentation of Intention
- Provide High Level State Summaries
- Provide Convenient Implementation of Predefined Operational Strategies
- Monitor Departure from Targets
- System Configuration Management

Mode Selection
- Primary Option Selection
- General Type Selection

Parameter Selection (WCU)

Parameter Selection (structures)

Display State Screen
- Decision Support for Water Managers
- Ad Hoc & Predefined Queries of Current and Recent State
- In use for last 3 years

Review Status Screens
- Primary Operator Interface
- Warning Messages
- Current Point and Control Status
- Last Operational Change Summary
- Availability Status
- Operations Control Interface

Objective Graph Trigger Manager
- Describe expectations for value of parameter in terms of severity of departure
- Rule Curves to manage water storage area
- Event Duration Scheduling

Rules and Plans
- Trigger Action Sets or Messages Based on Departure from Expectations Described in Objective Graphs
- Plans are named Action Sets
- Provide Documentation of Intentionality
- Allow Rapid Implementation of Emergency Strategy
- Convenient for switching between common water control strategies like water supply, flood control, regulatory releases, etc.

Rules
- Trigger Set – .true. triggers action set
- 1 (or more) Specific Objective graph zone
- Action Set
- Post or Retract Objective Graphs
- Activate or Deactivate Plans
- Generate Alert or Warning Messages
- Issue SCADA commands

Plans
- Functions
- Activate or Deactivate Plans
- Generate Alert Messages
- Issue SCADA commands
- Activate existing Objective Graphs
- Define temporary Objective Graphs active for duration of Plan – Overrides Default
- Triggered Manually or by Rules or other Plans

System Configuration Management
- Interface to track and launch background processes

- Utilities
- Parameter Value Generator
- Objective Graph Trigger Manager
- Web Publication Service
- Individual Operator Sessions

Application Evaluation

- Display State Screen
- In General Use 3 years
- Stable, Reliable, Flexible, High Utility
- X-windows Displays Inconvenient for Remote Access
- Review Status Screen
- In General Use 1 year
- Relatively Stable, Sophisticated Warnings best feature
- Would profit from tighter coupling to SCADA warnings
- System Configuration Management
- Background and concurrent process management workable but could use improvement
- Likely to be replaced with Microsoft based system
- Maintenance of Underlying Topography with proper constraints currently biggest problem

Advanced Warning Capability

- Standard SCADA type Point Based Warnings
- Sensor limit, rate of change, device failure, etc
- SCADA process failure – quality may be SCADA dependent
- Extended Point Based Warnings (not included in “basic” SCADA systems
- Design flow exceeded
- Maximum hydraulic head exceeded
- Energy Dissipation Problem
- Advanced System/Subsystem Analysis
- Multi-tiered parameter abstraction for current state plus simple rule base to define expectations provides powerful adjunct to traditional SCADA
- Allows abstractions like “can increase” , “route has no additional capacity”, and “partial flow blockage”

Future Direction

- Replace obsolete (1980’s era) SCADA system
- Adapt this SCADA independent decision support system overlay to work with new SCADA
- Continue to improve rule based warnings
- Water Budget Modeling
- Adapt modern GIS concepts to maintaining properly constrained topography

Desired ODSS Functional Categories (By Dr. Ken Stewart)

Dr. Stewart, the District’s Chief Consulting Engineer for the Information Technology Division, presented the desired ODSS functional categories to be included in a future Arc Hydro ODSS Tool. These are:

Objective Manager: This is where “soft” input data is collected, arranged, converted, manipulated in order to capture and formulate policies, rules as well as information that might come from framers and unexpected events, such as hurricane.

- Define and maintain operational strategies using:
- Objective graphs,
- Operational plans,
- Operational rules.
- Define and maintain operational zones
- Define and maintain operational plans.
- Define and maintain operational rules.
- Activate or deactivate operational plans:
- Manually (at a water manager’s discretion),
- By a triggered rule,
- By other automated process.
-
- ***State Estimator*: This unit would allow the state of the system to be defined and the values to be set, i.e. State Estimates. State of the system is a combination of sub systems that collectively make up the region of interest.**

- Define and maintain state variables and state estimates.
- Define and maintain state estimators.
- Define and maintain types of state estimators, where generic operations associated with these types can:
- Automatically determine the appropriate input(s) needed to generate the state estimate,
- Automatically determine the appropriate operation(s) to generate the state estimate
- Define and maintain types of state variables based on:
- The logical stream of new measurements generated by SCADA,
- Descriptions of state variables,
- Business rules defining when to use new measurements or state estimates to update dependent state variables,
- Descriptions of dependencies among state variables.
- Trace the dependencies on input(s) and state estimators of current state estimates.
- Provide support for automated data abstraction whereby information used in water management decision processes is derived from available sensor and external data, e.g.
- Stage/ Inflow/ Outflow for sites and water bodies.

- Doppler / ground-based real-time R/F data processing.
- Characteristic basin modes (flood control, water supply),
- Dynamic delivery system states (active paths, delivery schedules)
- Estimate (near-term) future states.
- Implement operational strategies based on:
- Current descriptions of operational strategies,
- Current state estimator values.
- Compare current state with active current objectives and:
- Verify that current state complies with defined operational criteria
- Suggest appropriate changes to operational state or
- Automatically control operational state
- Define and maintain associations among state variables.
- Automatically detect inconsistent associations among variables; assign and report probable causes.
- Provide support for decision support procedures that would optimize the compliance of future states against operational goals.

- ***Control Selector*: Based on Desired State information received from State Analyzer and possible fine turning by Operator a number of action will be taken and a Control Set will be generated and send to the field elements, i.e. sensors, water Control units, personnel in the field, etc.**

- Define and maintain control state changes in terms of SWN domain object states.
- Define and maintain supervisory control state changes
- Translate control state changes into appropriate SCADA command sets and:
- Submit command sets to SCADA, or
- Generate request for transmission to field personnel
- Track requests to field personnel including date, time, and name of person making request.
- When control state changes are initiated, establish criteria for successful completion, expected duration, and expected values of associated state variables.
- Detect and report failures of control set completion to initiating agent, appropriate personal, and maintenance processes.
- Monitor proper operation of sensors and actuators; assign and report probable causes of improper operation.

- ***General Requirements*: These functionalities are needed in order for the ODSS system to function as a whole and be ergonomic as well as providing support for logging and recording any transaction for the**

purpose of auditing and reporting as well as defining a general functional environment in support of overall decisions making process.

- Assist water managers and operators in assessing the current and recent operational state of the District in an accurate and timely manner.
- Describe the parts of the system from an Operational perspective.
- Provide visualization techniques for selected state information.
- Provide support for the automated detection, recovery and/or reporting of WMS process and process connection failures.
- Provide a human-machine interface (HMI) that provides ergonomic navigation to access, control, and visualization of all system information.
- HMI should include sensitized maps indicating geometry and connectivity of domain systems.
- Predefined and ad hoc queries into the current and near past system state.
- Current state screen (Review Status), which presents the current state of the system and provides a graphical user interface to control the field devices.
- Sophisticated warnings, enhanced decision support, advanced device control, and automatic documentation of intentionality.
- Recent History of Environmental Field Conditions. The recent history of monitored variables is also important. That is, it is not always sufficient to consider only the immediate state of environmental variables.
- Information Categories
- ***Objective Set*****: "soft" inputs that consist of operational regulations, Guidelines, Constrains, and in general subjective elements that have to be interpreted by Objective Manager so it can influence the decision making process.**

- Strategies to operate the system within the
- Operational regulations,
- Guidelines and
- Constraints
- The manual activation and deactivation of plans due to
- Flood control,
- Water supply
- (Etc) yet to be discovered
- District operational policy that include
- Text
- Rules
- Decision trees
- Flow charts
- Graphs
- Standard procedures and special conditions, for example

  - Standard operational guidelines for District structures.
  - Standard schedules for lakes, canals and conservation areas
  - Documented Operational Procedures for example
    - For operating the Lake Okeechobee) resulting from years of planning and political activity.
  - Also, special ad hoc procedures are sometimes established to handle perceived ecological (or other) situations that may arise.
- Notifications of Activities and Resource Usage of District customers and partners may be significant to operational decision-making. This includes notifications about
- Water supply use for irrigation and storage recharge purposes
- Water releases from agricultural and municipal drainage control sources
-
- *General operational activity that may impact District operations*.

- ***Current Objectives:*** **Are set of objective entities that has been formulated based on subjective input, i.e. Objective Set, that has been processed by Objective Manager**
- Specific operating instructions posted by water managers, such as:
- Prepared forecasts about probable near term precipitation events.
- Notifications with respect to the activities of customers and cooperative agencies.
- Text
- Rules
- Decision trees
- Flow charts
- Graphs
-
- ***Measurement Set*: Information that is generated by sensors in the field as well as some manually provided input. These values are the bases by which State Estimator generates Current State.**

- A stream of near real-time measurements describing current
- Hydrologic conditions especially
  - The water levels (stage) at strategic surface water and
  - Ground water sites in the District's surface water network
- The current operational state of District water control facilities. This includes the current state of water control devices such as
  - Gates,
  - Pumps, and
  - Flashboard bay levels.
- Meteorological conditions especially

    - Current rainfall rates.
    - Air temperature and pressure, wind speed and direction, et cetera, these variables are not crucial for operational purposes.
    - Real-time *precipitation rates* are important to operations.
- Secondary Data
- Diagnostic conditions related to the health of field and communications devices that provide monitoring and control functionality.
- Water Quality Conditions
- Operator initiated, (perhaps based on consideration of ODSS generated status messages), changes to the current working-or-broken status of devices used to monitor or control operations related states.

- ***Current State*: These values define the current state of the system, which are based on dynamic values (i.e. field measurements) and aggregate values such as flow that are the result of State Estimator**.

- Includes derived values at a specific location such as:
- Flow rate and
- Hydraulic head at a control structure.
- Aggregates values at specific sites such as
- Average stage in a water body or
- Net flow out of a canal reach.
- Four major aggregation types,
    - Water Control Units
        - Water Control Units may be visualized as the skeleton of a watershed. They are defined as an aggregate of water bodies that are controlled as a single unit.
        - Examples of parameters that can naturally be associated with a water control unit are mean or weighted mean water level, net outflow, or pass through flow. Less obvious derived parameters such as the difference between maximum and minimum water levels within the water control unit have proved beneficial.
        - A more sophisticated parameter associated with a water control unit monitors whether there is additional capacity to increase flood control releases from the area or water supply releases to the area.
    - Systems,
    - Flood Control Routes,
    - Water Supply Routes.
- Latest operational status of all devices.
- Near term predictions about the state of environmental conditions

- Forecasts of near term precipitation on a regular basis
-
- ***Desired State*: is acceptable from operational perspective and is indicated by the State Analyzer as a result of analyzing the Current State against Current Objective(s). For example the output of State Analyzer could be:**
- Set Water level from 2.0 m to an acceptable range of 2.5 to 4.0 m
- Set flow value to ½ Million Gallons per Hour
- Open the gate for a specific location for 10 min
- Discharge water from water body A to the available sinks

- ***Control Set:* Are the signal, either digital or analog, that are sent to the field, based on decisions made by Control Selector in order to bring the Current State of the system in compliance and in line with Desired State.**
- Control set to bring the state of the system to desired state via:
    - The change in operational state may be defined in terms of:
        - The specific state (position, speed, on/off state) of a structure's water control devices
        - A request to incrementally adjust the state of the structure to increase or decrease its current discharge rate, or
        - Initiate, terminate, or otherwise adjust the closed loop control algorithm of a site or a set of related sites (a multi-site).
- General Notifications
    - Requests to notify customers and partners with a specified message.
    -
- ***Other System Data*: Information indicated here are collected for monitoring and auditing the overall system behavior. At the same time various different modules may use this information.**
- *An Audit Trail*
    - *log the requests for operational state change. This log should include the reason for requesting the change, e.g. –*
        - *A plan activation,*
        - *A rule firing,*
        - *An operator reacting to an operator instruction,*
        - *Or some remark indicating why, and by whom, the change was requested.*
- *Reports to field personnel about perceived communications and equipment failures.*

Appendix C – Arc Hydro and Arc Hydro Tools

ARC HYDRO AND ARC HYDRO TOOLS

C.1 Introduction

Arc Hydro methodology provided in this appendix was extracted (sometimes verbatim) from the ESRI textbook on the subject: Arc Hydro – GIS for Water Resources, David R. Maidment, et al., ESRI Press, 2002.

After re-engineering the older Arc Info GIS in the late 1990's, ESRI initiated an effort to demonstrate the potential for custom application of the new object-oriented ArcGIS using specially design data models. The water resources data-modeling effort was undertaken by the Consortium in GIS for Water Resources composed of ESRI, the University of Texas at Austin, and the CRWR. These groups include representatives from industry, government, and academia. The water resources data model envisioned by the consortium was presented at several national meetings and technical conferences, and a prototype was built and tested at the CRWR. The final version of the data model was developed by ESRI and formally named the ArcGIS Hydro data model. Informally it is known as Arc Hydro.

Arc Hydro is a geospatial and temporal data model that operates within ArcGIS. Arc Hydro includes an associated set of tools that allow population of feature attributes in the data framework and of interconnected features in different data layers. These tools also support hydrologic analysis. This design characteristic allows the Arc Hydro data model (in association with the tools) to support hydrologic simulation models. Arc Hydro is not a model itself, but rather it is an intelligent interface between the geodatabase used by the model and a selected H&H model. Hydrologic simulation is accomplished by exchanging data between a simulation model attached to Arc Hydro and the independent hydrologic model using a dynamic linked library. Hydrologic simulation can also be performed by customizing the behavior of Arc Hydro objects.

In its basic framework, Arc Hydro supports the management of information for water resources tasks associated with natural systems (not piped networks) and serves as the platform for further elaboration of these tasks to fit a particular need. This can be accomplished by adding additional classes and attributes to the data model framework. Arc Hydro has no explicit data structures for description of groundwater features (aquifers, confining layers, etc.). It deals specifically with surface water features.

The SFWMD jurisdiction covers an extensive area of South and Central Florida. This geographical aspect requires the development of very large and complex project databases for hydrologic and environmental assessment and mathematical modeling. Projects over large areas make use of several different sources of GIS data and involve running very sophisticated hydrologic and hydraulic models.

Various branches of the SFWMD produce many types of GIS data that are used for many unconnected applications. Often, these data sources are misplaced, overwritten, and plain forgotten in some unknown repository with the consequence of data recreation for the same project area. Arc Hydro and its data framework provide a high degree of formality in the way the information is structured. This characteristic allows for a more systematic and efficient project execution and for the creation of a project archive that facilitates data reuse in subsequent projects in the same area from across the entire organizational structure.

C.2 Arc Hydro as Hydrologic Information System

Water resources management involves the observation (or calculation) of a water resources hydrologic process as a function of time for specific project tasks. In turn, these tasks require data such as rainfall, stream flow, water quality, and climate processes that can be measured and stored in a database for specific projects. The advent of GIS has allowed the concept of space to add a “spatial” dimension to the data storage for the accurate geospatial description of water resources features of the project’s landscape.

Although the time and location concepts of the water resources data have been available in the GIS world for many years, these have not been used in an inherent, cohesive or topologically optimum way. Arc Hydro enables the creation of a “hydrologic information system” of the project’s water resources domain through the synthesis of geospatial and temporal data supporting the hydrologic analysis.

C.3 The Arc Hydro Framework

The Arc Hydro data model framework is the “shell” of Arc Hydro. The framework stores information related to hydrography (physical environmental setting) and hydrology (the hydrologic cycle in the watershed). It includes data describing rivers, canal networks, watersheds, water bodies, and monitoring points. Additional components can be added to the basic framework to describe a more complex environmental/hydrologic setting.

Data, in standard GIS analysis, is gathered in two ways: as an “inventory” or “behavioral” approach. The “inventory” approach is where all features of the landscape are defined and arranged by location, properties, and individual behavior. This approach results in the classical “stack” or grouping of classes or data layers describing different kind of spatial features in a given geographic area.

The “behavioral” approach is the assessment of the behavior of the system in question by looking/identifying pertinent features that interact with others to define the whole system. This is the classical approach used by hydrologic modelers where the emphasis is not in a detail description of the environmental setting, but rather in the creation of a schematic project setting (lumped parameters) that emphasizes the features (or processes) pertinent to the model being use.

Arc Hydro provides an additional functionality to the standard data layering/description process. Arc Hydro provides the “connectivity” among the features in different data layers. Arc Hydro supports a formal network connectivity model of points and lines in its network analysis system and adds to the relationship between network junctions and related features such as watersheds, water bodies, and monitoring points. In this manner, watershed data that is collected in one layer and stream segments collected in another layer can be related by ArcGIS by not only spatial features but also by particular “intelligent” relationships of time and feature parameter value.

Arc Hydro provides a simple but systematic structure to link time series data of water management measurements to geospatial data at the locations where the measurements are made.

Table 1 below shows the thematic layers of the Arc Hydro data model. The layers reflect the standard geographic data model found as part of the ArcGIS software that is a representation of the real world and can be used by ArcGIS to produce maps, perform interactive queries, and execute analyses. These layers can be thought of as the "vocabulary" for describing the physical and climatic characteristics of the hydrologic cycle processes in a given environment and the resulting influence on surface water bodies, streams, rivers, and other water bodies.

Table 1- Thematic Layers of the ArcGIS/Arc Hydro Data Model

Layer	**STREAMS**
Map Use	Cartography and stream analysis
Data Source	Usually mapped by government mapping and resource agencies
Representation	Edges and nodes for the stream network, polygons for lakes
Spatial Relationships	Each edge has a flow direction and flows into another edge or sink
Map Scale and Accuracy	A typical map scale is 1:24,000, locational accuracy is about 10 meters
Symbology and annotation	Streams are drawn with blue lines with varying weights and patterns with line color, weight, and style

Layer	**HYDROGRAPHIC POINTS**
Map Use	Gage station on a stream network and features such as dams
Data Source	Usually mapped by government mapping and resource agencies
Representation	Junctions, network flags, and points on a stream network
Spatial Relationships	Points can be related to junctions on the network
Map Scale and Accuracy	A typical map scale is 1:24,000, locational accuracy is about 10 meters
Symbology and annotation	Typically drawn with colored circle markers by type

Layer	**DRAINAGE AREAS**
Map Use	Drainage areas are used to estimate water flow into rivers
Data Source	Derived from digital elevation models
Representation	Polygon with points at drainage outlets
Spatial Relationships	Each drainage area covers a stream section
Map Scale and Accuracy	A typical map scale is 1:24,000, locational accuracy is about 10 meters
Symbology and annotation	Shaded polygons can depict catchments or watersheds

Table 1 continued

Layer	**HYDROGRAPHY**
Map Use	The hydrographic layer in topograhic maps
Data Source	Mapped by government mapping agency
Representation	Point, line, polygon, and annotation for water features
Spatial Relationships	Streams feed rivers, rivers flow into lakes or oceans
Map Scale and Accuracy	A typical map scale is 1:24,000, locational accuracy is about 10 meters
Symbology and annotation	National cartographic standards are applied to water features

Layer	**CHANNELS**
Map Use	Hydraulic analysis
Data Source	Derived from surface model or land surveying
Representation	Cross sections and longitudinal profiles along a river channel
Spatial Relationships	Cross sections are perpendicular to flowlines
Map Scale and Accuracy	A typical map scale is 1:24,000 with location accuracy about 1 meter
Symbology and annotation	Channels, flowlines, and cross sections shown with graphs

Layer	**SURFACE TERRAIN**
Map Use	Deriving streams and drainage areas, also cartographic background
Data Source	Digital elevation models
Representation	TIN surface model or raster with elevations
Spatial Relationships	If raster, each cell has an elevation; if TIN, each face joins to form surface
Map Scale and Accuracy	A typical map scale is 1:24,000 with location accuracy about 1 meter
Symbology and annotation	Elevation is usually shown with graduated colors

Layer	**RAINFALL RESPONSE**
Map Use	Overlayed with rainfall grid to estimate flood or drought conditions
Data Source	Derived from combining layers such as soil, vegetation, and land use
Representation	Polygon
Spatial Relationships	Polygons tessalate an area
Map Scale and Accuracy	A typical map scale is 1:24,000, locational accuracy is about 10 meters
Symbology and annotation	Polygons can be shaded in proportion to rainfall response values

Layer	**DIGITAL ORTHOPHOTOGRAPHY**
Map Use	Map background
Data Source	Aerial photogrammetry and satellite collection
Representation	Raster
Spatial Relationships	Pixels tessalate the area imaged
Map Scale and Accuracy	Pixel resolution typically is 1 to 2.5 meters or better
Symbology and annotation	Tone, contrast, and balance of grayscale or color presentation

C.4 Arc Hydro Features and Database Integration

In the pre-ArcGIS version of Arc Info, the geospatial coordinate data describing the geographic features (Arc) was held separately from the attribute data describing those features (Info). In ArcGIS, all this data can be loaded into a relational database, so that the geospatial coordinate data of a GIS data layer is stored in just one field in a relational data table (Clark et al., 2001). This special form of a relational database is called a geodatabase, and it is the vehicle that facilitates the Arc Hydro data model. Because the relational database supports permanent relationships between its tables, feature-to-feature connections can be set up among the data layers via Arc Hydro.

Object oriented modeling technology such as Visual Basic for Applications became available in the 1990's. Visual Basic is the programming language used to build interfaces to the Microsoft Office Suite products such as for customizing Excel and Access beyond their native capabilities. This programming environment also allows applications from other languages such as FORTRAN or C, to be attached as dynamic libraries, and facilitates water resources simulation models written in FORTRAN or C to be tightly linked to the system.

The ArcGIS software also uses Visual Basic as its interface language, and its objects conform to the Component Object Model (COM) protocol. This means that full interchange between Microsoft Office applications and ArcGIS/Arc Hydro is possible.

Arc Hydro is a connected set of "objects" and "features" built on top of a generic set of objects and features called "Arc Objects" that are found as apart of the Arc GIS software. In ArcGIS object classes are defined as:

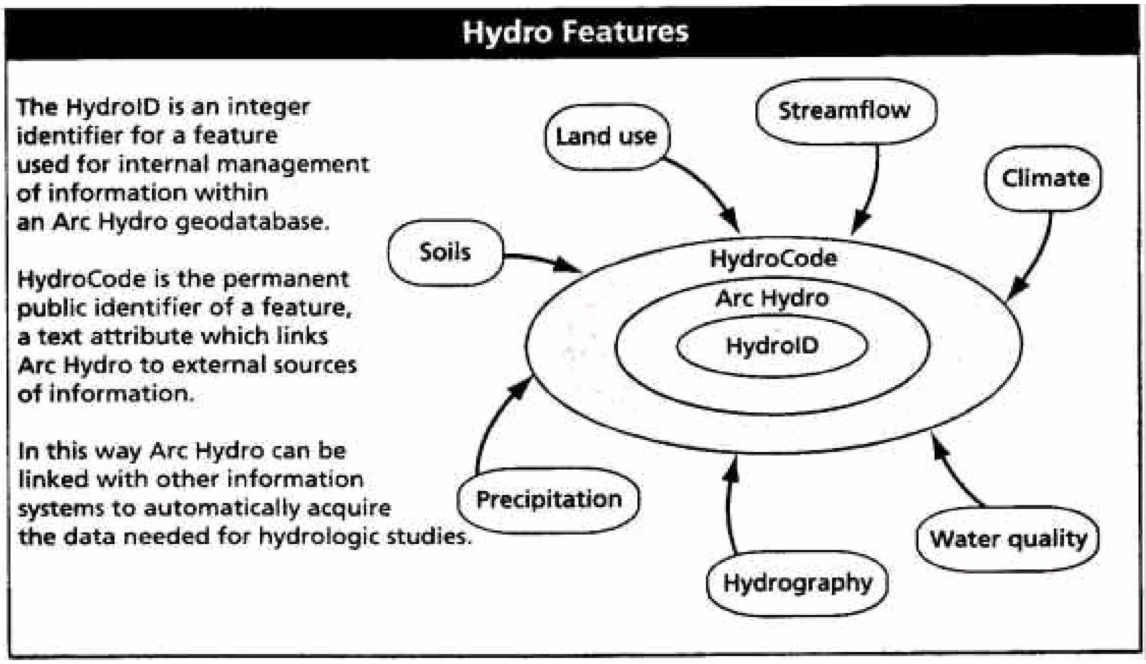
- *Objects*: Data tables that store only attributes such as a time series data table.
- *Features*: Data tables that store both spatial coordinates and attributes (points, lines, and areas or polygons).
- *Network features*: Special points and lines called junctions and edges whose data tables store the connectivity between junctions and edges, in addition to their attributes and spatial coordinates. Stream segments are represented by network features. Network features are subdivided into "*Simple*" and "*Complex*". Simple networks are formed by a single spatial feature and a single set of attributes. Complex networks are composed of several connected spatial features and a single set of attributes.

In the Arc Hydro design process, a specialized geometric network (hydro network) was developed that adds additional attributes to the ArcGIS "edge" and "junction" features to support water resources operations. The decision was made to use Simple rather than Complex junctions because HydroJunctions don't have complex switching patterns such as in electrical switch boxes. However, complex edges were used so that HydroJunctions could be placed on the interior of HydroEdges without breaking the edges. These interior junctions can serve as drainage area outlets, reference locations for gages, and points of water withdrawal or discharge.

The first step in customizing ArcObjects for hydrology is to define what makes Arc Hydro features different from any other kind of geographic feature in ArcGIS. In ArcObjects, the ObjectID is a unique identifier of any object within a feature class whose value is assigned at the time the object is created and is maintained permanently thereafter. In Arc Hydro, all features are hydro features and all hydro features carry two distinctive attributes:

- HydroID: An integer attribute that uniquely identifies the feature in the geodatabase
- HydroCode: A text attribute that is a permanently public identifier of the feature

Figure 1 below depicts the typical Arc Hydro configuration for HydroId and HydroCode attributes.



The HydroID is defined using two tables, the LayerKeyTable and the HydroIDTable. These tables are generated automatically by Arc Hydro upon the assignment of a HydroID. Each time a new ID is assigned, a counter is updated so that same HydroID is never assigned again within a geodatabase.

All hydro features can be associated with any other hydro feature by storing the HydroID of the first feature as an attribute of the second. By this process, the drainage areas may be associated with the junctions of the network to which these areas drain, thus defining the correct path of raindrop movement between the land surface and the discharge point of the water flow network. Similarly, time series data can be associated with a particular hydro feature simply by storing the HydroID of that feature with every associated time series data record.

Arc Hydro attributes ending in ID (e.g., HydroID, DrainID, FeatureID) indicate an integer identifier, and attributes ending in Code (e.g., HydroCode, ReachCode, RiverCode) indicate a string or text identifier.

The Arc Hydro framework provides a simple, compact data structure for storing the most important geospatial data describing a water resources system. The framework contains information organized in several levels:

- *Geodatabase*: Such as Microsoft Access if a personal application is required, or an enterprise database such as Oracle or SQL Server for users throughout a network.
- *Feature Dataset*: A folder that stores feature classes within the geodatabase. The feature data set has a defined map projection, coordinate system, and spatial extent.
- *Geometric network*: This is where information that topologically connects HydroEdges and HydroJunctions is stored.

- *Feature class*: This is where information on individual geographic features is stored.
  HydroEdge – A network of lines describing streams and water body centerlines
  HydroJunction – A set of junctions located at the ends of flow segments and at other strategic locations of the flow network (such as control structures). HydroEdges and HydroJunctions are topologically connected in ArcGIS geometric networks called the Hydro network.
  Waterbody – Significant ponds, lakes, bays, and other water bodies of the water system.
  MonitoringPoint – A set of points representing gage locations where water is measured.
- *Relationship*: This is where features from one class are related to those in another.

Since HydroJunctions are topologically linked to HydroEdges in the hydro network, the classes in the Arc Hydro framework are connected in to an integrated data structure. This supports tracing water movement from one feature to another through the project's landscape or physical domain. The creation of an integrated database, instead of a collection of data layers, is a key accomplishment of the Arc Hydro design in Arc GIS.

C.5 The Arc Hydro Data Model Components

The Arc Hydro data model divides water resources data into five components:

- *Network*: Connected set of points and lines showing pathways of water flow
- *Drainage*: Drainage areas and stream lines defined from surface topography
- *Channel:* A 3-D line representation of the shape of river and stream channels
- *Hydrography*: The base data from topographic maps and tabular data inventories
- *Time series*: Tabular attribute data describing time-varying water properties for any hydro feature.

C.5.1 Hydro Networks

The hydro network is the backbone of Arc Hydro. The topological connection of its HydroEdges and HydroJunctions in a geometric network enables tracing of water movement upstream and downstream through streams, rivers, canals, and other water bodies of the water system. Locations on the hydro network are defined by river-addressing schemes (linear referencing), that defines where points are located on lines within drainage areas, allowing measurement of flow distance between any two points on a flow path. Centerlines can be drawn through all real features to create a continuous, single-line network throughout the river system. A flow line traces the main direction of water movement in a one-dimensional flow. A key virtue of the flow line is that it remains the same regardless of the size of the stream, river or canal. Flow lines can be drawn through lakes from the point where a tributary inflow enters the lake to the point of discharge at the lake outlet.

HydroEdges are divided into two subtypes:

- *Flowlines* (EdgeType=1) that trace water movement through the streams, rivers, and water bodies, and

- *Shorelines* (EdgeType=2) that form the interface between land and water bodies. Shorelines include those of lakes and reservoirs, coastlines to the sea or ocean, and bank lines for wide streams or rivers.

The attribute Ftype can be used to differentiate among the types of HydroJunctions and HydroEdges in a network.

Flow direction is assigned to each HydroEdge in order to direct flow toward the nearest sink or outlet for discharge of water from the network. Hydro Navigation is a process of tracing the water movement from feature to feature through the landscape or project domain. Arc Hydro supports three (3) types of navigation:

- Network navigation: Carried out using the ArcGIS network tracing tools when applied to the hydro network.
- Next downstream navigation: Carried out on HydroJunctions or other feature classes that have a NextDownID attribute assigned to them.
- Schematic Navigation: Carried out on a pair of separate feature classes, called SchematicLink and SchematicNode, which serve to link strategic locations with straight lines in a schematic diagram.

River addressing is used to locate objects on a river or stream system. Arc Hydro supports *Absolute* and *Relative* addressing in a water system. All the HydroEdges and HydroJunctions in Arc Hydro carry the attribute LengthDown which is the distance to the nearest network sink or outlet measured in kilometers. This is a very useful tool because it assigns a measure of flow distance to the outlet everywhere within the network. The HydroEdge attribute ReachCode identifies a set of HydroEdges linearly connected to form a single river reach, usually defined between stream confluences.

Objects located by linear referencing on a hydro network are called hydro events. Hydro event feature attributes are the HydroPointEvents (point location on a HydroEdge), or the HydroLineEvents (line between two identified points on a HydroEdge). Hydro events carry a ReachCode attribute to identify which HydroEdge or set of HydroEdges they reference. Once events are defined, any number of attributes can be added to them. Events are an alternate way of relating information to the hydro network such as information about discharge points found in regulation schedules.

C.5.2 Drainage Systems

The Arc Hydro toolset contains functions to accomplish automated drainage area and stream network delineation from digital elevation models (DEM's). The Arc Hydro model accepts drainage areas and connects them to the hydro network no matter whether the areas were automatically or manually delineated, and allows for the fact that the mapped stream hydrography may not be entirely consistent with the land-surface terrain or hypsography used to determine drainage area or boundaries.

In Arc Hydro the following hierarchical definition of geographical drainage area applies:

- Basin: Drainage areas that are usually named after the principal rivers, streams, or canals of a region. Basins may serve as special packaging units for Arc Hydro data sets.

- Watershed: A subdivision of a basin into drainage areas for a particular hydrologic purpose. Watersheds may drain to points on a river network, to river segments, or to other water bodies.
- Catchment: A subdivision of a basin into elementary drainage areas defined by a consistent set of physical rules.

In Arc Hydro, it is always recommended to develop an Arc Hydro geodatabase for each basin in a water system.

The process of merging sub-basin Arc Hydro geodatabases into a regional Arc Hydro geodatabase is facilitated by special treatment of the HydroID assignment to the features in each sub-basin. Combining a regional hydro network with locally delineated drainage areas is a powerful device for regionalization of water resources management practices.

C.5.3 River Channels

This is the Arc Hydro model component that describes the data requirements for river morphology necessary for river modeling and floodplain delineation. Arc Hydro has tools to apply digital terrain model (DTM) methodology for representation of the surface and or channel topography. Data required for river models can be grouped into three (3) categories:

Hydraulic data: Consisting of continuous measurements such as discharge hydrographs, stage or water surface elevations, tidal records, spot measurements of stage, rating curves, etc.
Topographic data: Describes the geometry of the simulated river system such as width, cross-sectional areas, volume of inundated floodplains, etc.
Qualitative data: data that identifies the physical conditions that determine flood development patterns such as the existence of berms within the floodplain, dykes, breaches, elevated roads, etc.

Arc Hydro stores and manages channel information consisting of two feature classes and one object class. Channel features *CrossSection* and *ProfileLine* are derived from the ChannelFeature abstract class.

ChannelFeature: the purpose of this feature class is to gather attributes that are common to channels such as cross thalweg and cross sections. Its attributes are *ReachCode* and *RiverCode.* ReachCode is the identifier that tags each water feature uniquely within each water system in the United States. RiverCode is another identifier of the river, defined by the river name or by the concatenation of the latitude and longitude of its outlet location.

The river system can be further defined in Arc Hydro with cross section shapes. CrossSections are linear features that define the shape of the channel transverse to the direction of flow. The CrossSectionPoint object class stores traditionally surveyed cross section points. CrossSection events are tables corresponding to measured values along a cross section such as roughness, land use type, left bank/right bank locations, left/right floodplain location, etc. The HydroEvent objects such as HydroPointEvents or HydroLineEvents are used to define properties at particular points or along particular regions of the cross sections.

In Arc Hydro, longitudinal views of the channel are represented with ProfileLines. These are linear features that define the longitudinal profile of the channel parallel to the direction of flow (e.g., thalweg, left bank, right bank, left floodline, and right floodline). The left and right floodlines represent the extent of inundation in the left and/or right floodplains respectively. The ProfileLine has two attributes: Ftype which is the code specifying the feature represented by a profile (thalweg, bankline or floodline), and ProfOrigin which identifies the source of data and method used to capture the shape of the ProfileLine.

C.5.4 Hydrography

Hydrography is the map representation of surface-water features in the landscape or project domain. Hydrography data sources include point, line, and area data layers from map hydrography, point features derived from tabular data inventories and hydro response units that account for vertical exchange of water in the hydrologic cycle of the land surface. Arc Hydro was designed so that its features and attributes correspond with national and regional hydrography sets, including the National Hydrography Database (NHD).

Arc Hydro provides a feature class for each dimension: *HydroPoints, HydroLines*, *HydroAreas. HydroResponseUnit* is included in Hydrography to accommodate any type of response unit needed by the user.

HydroPoint classes: MonitoringPoints, Dam, Bridge, Structure, WaterWithdrawal, WaterDischarge, and UserPoint.

Dam, Bridge and Structure points are intended to represent features, man-made or natural, that restrict or change the movement of water. WaterWithdrawal and WaterDischarge represent points at which flow is removed or added to the stream network. Monitoring Points store the locations of gages that measure water quantity or quality, including water quality monitoring stations, stream-gage stations, rain-gage stations, and any other type of fixed data collection point. UserPoints are intended to store point data that does not fit into the model anywhere else.

HydroLines: are designed to contain line features that are important for the cartographic representation of a water study area. These include natural streams and rivers, man-made canals, ditches, pipelines that carry water under ground, and artificial paths that represent the centerlines of lakes and other water bodies.

HydroArea: Ordinary landmark areas such as no wake zones are stored as HydroAreas. However, Waterbody is a child class of HydroArea. Water bodies on a river channel are to be included in the network through the Catchment, Watershed or HydroResponseUnit features classes.

HydroResponseUnit: is an area of the land surface that has homogeneous precipitation, land surface characteristics or both. HydroreponseUnits account for the vertical exchange of water through the hydrologic cycle and are used in hydrologic modeling simulations to accurately describe and predict how water will move through the environment.

C.5.5 Time Series

The flow and quality of water are defined by time series measurements taken at gages and at sampling points. Time series formats vary from uniform or regular intervals, to irregular infrequent readings. GIS data models do not normally consider temporal information and the synthesis of time series data is of particular challenge to Arc Hydro.

Arc Hydro does not try to duplicate commonly used time series data such as that of the USGS National Information System or the EPA's Storet water quality system. Instead, Arc Hydro provides a repository for time series data derived from water measurements or simulation models.

Time series' are captured and stored in Arc Hydro in a variety of formats. An Arc Hydro user may acquire, store, and deliver an entire hydrologic data set, including time series data files from monitoring and catchment stations. Time series data can be depicted in Arc Hydro in 3-D format where the three (3) coordinate axes are space, time and the variable being measured (indexed as "L", "T" and "V").

Time series data in Arc Hydro is managed through a coded value domain called *TSDataType.* There are four (4) value types:

- Instantaneous data – A condition at a given instant of time
- Cumulative data – The accumulated value since the beginning of the record
- Incremental data – The difference in cumulative values at the beginning and at the end of a time interval
- Average data – The average rate over a time interval, calculated as the incremental value divided by the duration of the data interval.

Arc Hydro Tools Overview

Version 1.1 Beta 2, March 2003

Table of Contents

Introduction to Arc Hydro

Arc Hydro is an ArcGIS-based system geared to support water resources applications. It consists of two key components:

- Arc Hydro Data Model
- Arc Hydro Tools

These two components, together with the generic programming framework, provide basic database design and set of tools that facilitate analyses often performed in the water resources area. Arc Hydro is intended to provide the initial functionality that can then be expanded by adding to it database structures and functions required by a specific task or application.

Introduction to Arc Hydro Tools

The Arc Hydro tools are a set of utilities developed on top of the Arc Hydro data model. They operate in the ArcGIS environment. Some of the functions require the Spatial Analyst extension. The tools are accessed through the Arc Hydro Tools toolbar, where they are grouped by functionality into five menus and six buttons.

- Menus:
  - Terrain Preprocessing. Tools in this menu deal with processing of Digital Elevation Model (DEM). They are mostly used once in order to prepare spatial information for later use.
  - Watershed Processing. Tools in this menu deal with watershed and subwatershed delineation and basin characteristic determination. They operate on top of the spatial data prepared in the terrain preprocessing stage.
  - Attribute Tools. These tools provide functionality for generation of some of the key attributes (fields) in the Arc Hydro data model. Some of the tools require existence of a geometric network.
  - Network tools. These tools generate or manipulate properties of geometric (hydro) network.
  - ApUtilities. These are tools for management of Arc Hydro project properties. In general, they will be seldom used.
- Buttons:
  - Flow Path Tracing
  - Point Delineation
  - Batch Point Generation
  - Assign Related Identifier
  - Global Delineation
  - Trace By NextDownID Attribute

The tools have two key purposes. The first purpose is to manipulate (assign) key attributes in the Arc Hydro data model. These attributes form the basis for further analyses. They include the key identifiers (such as HydroID, DrainID, NextDownID, etc.) and the measure attributes (such as LengthDown). The second purpose for the tools is to provide some core functionality often used in water resources applications. This includes DEM-based watershed delineation, network generation, and attribute-based tracing.

The functionality of Arc Hydro tools is expected to grow over time. They have been implemented in a way that allows easy addition to their functionality, either internally (by adding additional code) or externally, by providing additional functionality through the use of key Arc Hydro data structures.

Tools list

The tools will be presented by their grouping in the user interface (menus). The ApUtilities tools will not be addressed here, as they are general-purpose utilities not related to the functionality of Arc Hydro tools.

Terrain Preprocessing

Tool	Description
DEM Reconditioning	Enforce linear drainage pattern (vector) onto a DEM (grid). Implements AGREE methodology.
Fill Sinks	Fill sinks for an entire DEM (grid).
Flow Direction	Create flow direction grid from a DEM grid.
Flow Accumulation	Create flow accumulation grid from a flow direction grid.
Stream Definition	Create a new grid (stream grid) with cells from a flow accumulation grid that exceed used-defined threshold.
Stream Segmentation	Create a stream link grid from the stream grid (every link between two stream junction gets a unique identifier).
Catchment Grid Delineation	Create a catchment grid for segments in the stream link grid. It identifies areas draining into each stream link.
Catchment Polygon Processing	Create catchment polygons out of the catchment grid.
Drainage Line Processing	Create streamlines out of the stream link grid.
Adjoint Catchment Processing	Create adjoint catchment polygon for each catchment in the catchment polygon feature class. Adjoint catchment is total upstream area (if any) draining into a single catchment.
Drainage Point Processing	Create a drainage point at the most downstream point in the catchment (center of a grid cell with the largest value in the flow accumulation grid for that catchment).
Slope	Create a slope grid for a DEM.
Slope greater than 30	Create a grid showing the cells having a slope greater or equal to 30%.
Slope greater than 30 and facing North	Create a grid showing the cells having a slope greater or equal to 30% and facing north.

Watershed Processing

Tool	Description

Batch Watershed Processing	Create a watershed for every point in the batch point feature class. Results are stored in a watershed (polygon) feature class. Watersheds are overlapping (if points are on the same stream).
Batch Subwatershed Processing	Create a subwatershed for every point in the batch point feature class. Results are stored in a subwatershed (polygon) feature class. Subwatersheds are non-overlapping (if points are on the same stream).
Drainage Area Centroid	Create a point at the centroid of each polygon in a polygon feature class and store it in a point feature class.
Longest Flow Path	Create a line following the longest flow path based on the steepest descent (as defined by the flow direction grid) in a catchment or watershed.

Attribute Tools

Tool	Description
Assign HydroID	Assigns a unique identifier (HydroID) to a feature. HydroID is unique across a geodatabase.
Generate From/To Node for Lines	Generates from-node/to-node topology based on physical line connectivity for a line feature class (does not require hydro network). Nodes are defined as ends of lines. They are not created as a separate feature class, but rather just identified and accounted for internally.
Find Next Downstream Line	Find the HydroID of the next downstream linear feature class and store it in the NextDownID field of the feature. The directionality is based on the digitized direction. Connectivity is established by the physical connection of the linear features (does not require hydro network).
Calculate Length Downstream for Edges	Calculate length from the downstream end of a hydro edge to the outlet of the hydro network (requires hydro network). The length is stored in the LengthDown field.
Calculate Length Downstream for Junctions	Calculate length from a hydro junction to the outlet of the hydro network (requires hydro network). The length is stored in the LengthDown field.
Find Next Downstream Junction	Find the HydroID of the next downstream junction and store it in the NextDownID field of the junction feature (requires hydro network).
Store Area Outlets	Identify most likely hydro junction that drains an area. The HydroID of that junction is stored in the JunctionID field for the area feature class.

Consolidate Attributes	Summarize the values of a numerical attribute of a feature class and store them in a field in another (or same) feature class. Relationship between the from and the to feature class is established through related IDs. Operators include sum, min, max, average, median, mode, standard deviation, and count. User specifies the from and the to feature classes, what field to summarize and in what field to store the summarized values. The tool can use the same feature class as both from and to objects to operate on.
Accumulate Attributes	Summarize the values of a numerical attribute of a feature class and store them in a field in another (or same) feature class. The tool selects the upstream objects by tracing either using the geometric network or a NextDownID relationship, and summarizes the selected objects. Operators include sum, min, max, average, median, mode, standard deviation, and count. The selectable objects are either the traceable objects, or can be in an ID-related feature class (using existing relationship classes). User specifies the from and the to feature classes, what field to summarize, and in what field to store the summarized values
Display Time Series	Display the values of the selected parameter as a function of time.
Get Parameters	Extract characteristics associated to polygon features: area, average elevation, maximum elevation, minimum elevation, relief, slope, land cover, precipitation.

Network Tools

Tool	Description
Hydro Network Generation	Generate a hydro network (hydro edges and hydro junctions) from drainage lines, catchments, and drainage points. The function updates all the connectivity fields in input feature classes.
Node/Link Schema Generation	Generate schematic (node-link) network by connecting centers of catchments/drainage areas and junctions, and junctions and junctions. Connectivity is established through connectivity fields (attributes), not physical connectivity.
Store Flow Direction	Store information about hydro (geometric) network element's directionality into an attribute of the feature matching the element.
Set Flow Direction	Define flow direction for a geometric network based on digitized direction or an attribute for the feature.

Buttons

Tool	Description
Flow Path Tracing	Trace the downstream path, based on the steepest descent, from a user specified point to the edge of the DEM (uses flow direction grid).

Point Delineation	Delineate a watershed for a user specified point (interactive) based on the preprocessed DEM.
Batch Point Generation	Add user specified point to a batch point feature class. This point feature class can be used as an input to the batch watershed and subwatershed delineation functions.
Assign Related Identifier	Interactively assign a value of a field in a source feature to a field in the target feature. User specifies both the source and target feature classes and fields.
Global Point Delineation	Delineate a watershed for a user specified point (interactive) based on a set of preprocessed geographic units tied together by a geometric network. Compute global parameters.
Trace By NextDownID Attribute	Using the attribute relationship established through NextDownID field, trace from a selected location upstream, downstream, or in both directions. The final selected features can include the objects selected through the trace, and/or ID-related objects (using existing relationship classes).

What's new in Arc Hydro 1.1 Beta 2

Arc Hydro 1.1 Beta 2 incorporates the following modifications:

- most functions are now ArcView 8.x compliant (note: the functions dealing with editing/creating complex objects such as network objects cannot work with Arc View)
- new functions have been added.

The main changes are the following:

Non-ArcView compliant functions

Arc Hydro is now ArcView 8.x compliant, except for the following functions:

- Hydro Network Generation
- Calculate Length Downstream for Edges
- Calculate Downstream for Junctions
- Find Next Downstream Junctions
- Store Flow Direction
- Set Flow Direction

Note: ArcView allows editing only data residing in a non-complex workspace, i.e. ArcView cannot edit simple feature classes that reside in a complex workspace (e.g. dataset with a geometric network, even though the simple feature classes do not belong to the network).

New functions

The following function have been added to Arc Hydro:

- Slope (Terrain Preprocessing)
- Slope greater than 30 (Terrain Preprocessing)
- Slope greater than 30 and facing North (Terrain Preprocessing)
- Get Parameters (Attribute Tools)

Modified functions

- Display Time Series (Attribute Tools).

Note: 2 additional time series functions are available by adding to ArcMap the file TimesSeriesManager.dll (Tools>Customize>Add from file...), which adds the TimeSeriesTools toolbar).

Appendix D – Pre-Charrette User Questionnaire Results

SFWMD Extended Arc Hydro
Pre-Charrette Questionnaires
September 18, 2003

Pre-Charrette (Short) Questionnaire
- **Who** are you, Who do you work for
- **What** GIS data do you use, create, modify
- **When** – Timeframe - Current, Past, Future
- **Where** – Typical Project Scales
- **How** – Consensus on Issues from the Kickoff

Summary
- 20 Responses
    - All four projects represented
        - C-4 (Flood)
        - Kissimmee Restoration (Hydroperiod)
        - Operations Decision Support System (ODSS)
        - Regional Simulation Model (RSM)
    - AND Enterprise GIS (E-GIS)
- Summarized by group and consolidated – highlights

Data Layers - Usage
- **ALL Groups**
    - Users of Full Hydrologic/Hydraulic Network
- **ALL Groups Except ODSS**
    - Create and Modify almost ALL major GIS layers
        - Implies large potential overlap in effort
        - GIS data creation and maintenance
- **Goal of Moving to a Shared Geodatabase**
    - Reinforces need for Coordination of GIS data creation and maintenance

Timeframes – What are the temporal ranges of the data that you deal with

- **ODSS** +/- 1 year
- **RSM** +/- 30 years
- **Hydroperiod** -30 years/+1year
- **C-4** – 5-Year Historical Rainfall, Current Features, 50-Year Projections for CERP

- Everyone wants to have **long-term access to the data used in any given project or analysis** but does not require the project archive to be widely shared.

Respondents Agree

- Functional Scales
  - Regional, Sub-regional, Local (but define)

- One set of Basins and Sub-basins
  - HUC-like level classification for aggregation
  - Aggregation to support all functional scales

- Data Certification for each Functional Scale

- Run Multiple Models from the Same GIS Data

- Checkout Subsets of Data for What-if Scenarios

  - Not necessary to maintain project level archive data or what-if scenarios in Core Arc Hydro. Maintain as project geodatabases on project servers.

For the "Resolve List"

- **National Standards = Task 2 Detail**
  - Where to use, where to adapt, where to ignore

- **Multiple Scales and Data Storage details = Data Storage Detail for Task 2**
  - Store only highest resolution data with software to generalize.
  - or Support a "pyramid" of scale-dependent mirrored features

- **Versions, Time-Indexing, "What-if", and the Enterprise Database ***
  - Maintain project-specific versions at project level as personal geodatabases
  - or
  - Maintain persistent multiple versions in the Enterprise Database/Time-indexed features/attributes and versioning
  - or
  - Alternative options/hybrids/future capabilities (ESRI)

  *** Versions, Time-Indexing, "What-if", and the Enterprise Database** were addressed at the Charrette and following the Charrette. The consensus approach is to maintain project-specific geodatabases at the project level with "hooks", i.e. relational fields, that allow the project-specific geodatabases to be linked to the Core Arc Hydro framework. The project-specific geodatabases comprise extracts from the Core Arc Hydro

Framework and additional features only required by the project. Project-specific geodatabases are not part of the core implementation, but needed to be conceptualized in order to properly design the core Arc Hydro. In addition, timeseries data extracted for project input through Core Arc Hydro are stored with the project. Core Arc Hydro provides links to these source Timeseries that may be stored in Arc Hydro or may be stored in another Enterprise database. Finally, core Arc Hydro will include record-level attributes that address object life cycles, for example, In-Service Date and Removed Date.

Pre-Charrette Questionnaire

Who						
Name: Consolidated All			**Division:**	ALL		
Position Title:			**Supervisor:**			
E-mail address:			**Group:**	ALL		
What						
Please check the approriate boxes indicating how you use each GIS layer:						
Hydrologic Data	Create	Modify	Use Regional	Use Local	Use "What-if" Versions	
Basin Boundaries	3	7	15	11	7	
Subbasin boundaries	5	6	13	11	7	
Digital Terrain Models/Digital Elevation Models	7	6	8	7	4	
Rainfall	8	8	16	11	7	
Stream Gauge	5	5	13	10	3	
Hydrographic Framework (Rivers, Streams and Canals)	8	8	15	12	8	
Hydraulic data	Create	Modify	Use Regional	Use Local	Use "What-if" Versions	
Pipes- Culverts	7	8	14	13	6	
Pipes- Conveyance Structures	7	8	15	13	6	
Channels and Ditches	9	10	12	12	6	
Control Structures	7	8	15	13	7	
When						
Data Timeframe Requirements. Check the boxes indicating your data needs.						
Past	Last month	Last Year	Last 5 years	Last 10	Last 20	
Feature Data (Streams, Canals, Basins, etc.)	12	11	8	6	6	
Time Series Data (Rainfall, Stream Gauge, etc)	15	13	11	8	8	
Future	Next Month	Next Year	In 5 years	In 10 years	In 20 years	
Feature Data (Streams, Canals, Basins, etc.)	12	9	6	3	4	
Time Series Data (Modeled Water Conditions)	11	8	6	3	4	
	Average	eGIS	C-4	Hydroperiod	ODSS	RSM
After using feature data to do an analysis, how long (years) do you need that exact same data to be available to rerun the analysis in the future (assuming the GIS system maintains the existing features and past states are archived for a specified period)	100	36	7	30	2	Forever
After using timeseries data to do an analysis, how long (years) do you need that exact same data to be available to rerun the model in the future?	100	36	7	30	2	Forever
Where						
Project Location(s) and scales						
What is the percentage distribution of project extents:	District-wide	**Multi-basin**	**Single Basin**	**Sub-basin**		
Row should total 100%	31%	34%	21%	14%		

How						
What is your opinion about the following statements:	Agree, Disagree, Unsure, Not Applicable	eGIS	C-4	Hydroperiod	ODSS	RSM
For the conceptual framework, three functional scales are enough - Regional, Sub-regional, and Local	A	A	A	A	A	A
We should store only the highest resolution data for any area and have attributes and tools to generalize high resolution data for more regional use.	?	D	U	A	A/D/U	A
To Be Resolved						
We should design the database to store different datasets for regional, subregional and local data	?	A	U	A/D/U	A/D/U	A
We should store one set of basins and sub-basins and define a classification level like the HUC system that permits sub-basins and basins to be aggregated for sub-regional and regional analysis	A	A	A	A+	A	A
or						
Some of my projects will not work properly by aggregating smaller basins into regional basins. They require the use of separate basin layers at different scales scales.	D		D	A/D/U	A/D/U	D
Data certification for use at each functional scale is important to me	A	A	A+	A	A	A
To Be Resolved Case by Case -- NATIONAL STANDARDS-- NOT WHEREVER POSSIBLE; BUT, WHERE COMPATIBLE WITH S. FLORIDA						
I would prefer to adhere to National Standards whenever possible (HUC numbers, Reach codes, etc.)	?	A	D	A/D/U	A/D/U	D
It is important to me to be able to run multiple models from the same input data.	A	A	A	A+	NA	A/D/U
or						
I normally run only one model or analysis on a given set of data.	D	D	D	D	D/NA	D
If the database had a way to check out subsets of data and create multiple versions for "what-if" scenarios, I would use this feature.	A	A	A	A	A	A
I need to share some or all of these **"what-if"** subset versions of the database with others, and maintain them **as part of the Enterprise database**.	?	A	D	U	D/U/NA	A
or **To Be Resolved**						
I could keep **special versions and subsets** of the database with my projects for future reference **without storing them in the Enterprise** database.	A		A	A	A/D/U	A/D/U